FIFTH ANNUAL REPORT ON CACAO RESEARCH 1935

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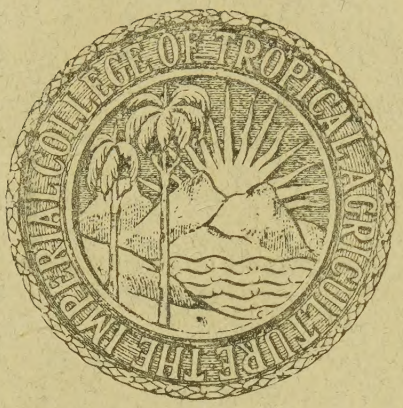
6 JULY 1936
INSTITUTE



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CONTENTS.

PAGE.

A.—BOTANICAL SECTION.

THE POSITION OF BOTANICAL RESEARCHES AT THE END OF 1935 3

THE VEGETATIVE PROPAGATION OF CACAO:

VI. GENERAL NOTES ON TECHNIQUE WITH CUTTINGS 4

VII. ROOT SYSTEMS OF CUTTINGS 7

THE COMPLETION OF SELECTION, 1935 7

STUDIES OF FRUITFULNESS IN CACAO:

VIII. SECOND YEAR OBSERVATIONS IN AN EXPERIMENT DESIGNED TO TEST THE GROSS EFFECTS OF APPLICATIONS OF NITROGEN, POTASSIUM AND PHOSPHORUS ON THE CACAO TREE 16

IX. DIFFERENCES BETWEEN HIGH BEARING AND LOW BEARING CACAO TREES IN RESPONSE TO INORGANIC MANURES 20

X. PHYSIOLOGICAL EFFECTS OF APPLICATIONS OF NITROGEN, POTASSIUM AND PHOSPHORUS ON THE CACAO TREE 22

B.—CHEMICAL AND ECOLOGICAL SECTION.

SUMMARY OF PREVIOUS RESULTS AND THE CHEMICAL PROGRAMME OF 1935 25

CACAO SOIL SURVEYS 30

MANURIAL EXPERIMENTS ON CACAO 34

THE MANGANESE CONTENT OF WEST INDIAN CACAO SOILS 43

A NEW METHOD OF CURING SMALL QUANTITIES OF CACAO 48

FIFTH ANNUAL REPORT ON CACAO RESEARCH, 1935.

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FIFTH ANNUAL REPORT ON CACAO RESEARCH, 1935.

A.—BOTANICAL SECTION.

THE POSITION OF THE BOTANICAL RESEARCHES AT THE END OF 1935.

By E. E. Cheesman.

With the completion of the fifth year of Cacao Research, the period of preliminary investigations, comes to a close, and it is time to take stock of it as a whole, as well as to look forward to the next phase that is just beginning.

Propagation.

The original object of discovering how to propagate cacao vegetatively on its own roots was partially attained in the first year, when Mr. Pyke reported success with softwood or semi-hardwood cuttings. The technique has been continually improved in the following years, and a description of its details as it is used to-day finds a place in this Report. No doubt further improvements can and will be made in the future, but the stage that has been reached may be regarded as already beyond the experimental, in the narrower sense of the term. With some of the older cuttings already beginning to bear fruit, it can be seen that their appearance is that of normal trees in every way, and the photographs of root systems included in the present Report show that their behaviour is satisfactory below ground as well as above. This is all that was expected of the preliminary stages. Standard material can now be raised, and the way is open to investigations of stock influence in budding or grafting, to reduction of variance in field experiments, and to all those numerous researches which have hitherto had to wait for genetically uniform material.

Selection.

Dr. Pound completes in this Report the Imperial College selection list, with descriptions of the remaining trees needed to bring his previous selections up to 100. This again marks the end of a phase. Attention in the future will by no means be confined entirely to 100 types, but these are sufficient to demonstrate the principles of selection, and indeed as many as can be handled for that purpose. Further selection on similar lines falls outside the province of the Research Scheme and must be a matter for local efforts in countries where it is necessary. Here also the result has been the establishment of standards, in this case a range of types against which any new acquisitions can be compared whether they come from the Criollo end of the cacao complex or from quite different origins.

Studies of Fruitfulness.

Our studies of the botanical factors contributing to yield in cacao are not of a kind that can come to any definite end, yet even they have reached a point that marks a stage. The natural behaviour of mixed trees in the field has been observed and recorded over several years as a necessary basis for analysis of the interactions between constitution and environment. On the constitutional side, differential pollen compatibilities and various degrees of partial sterility have been revealed, which for their further study need uniform material under varying conditions. On the environmental side, drastic manurial treatments have been used in an attempt to distinguish between the effects of mineral nutrition and those more directly dependent on weather or the periodicity of the trees themselves. A paper included in the present Report shows that these drastic treatments failed in two successive years to affect in any way the natural periodicity of flushing, flowering, fruit-setting, and loss of young fruits, over the population as a whole. For the time being, these studies seem to have gone nearly as far as they can be taken on mixed seedling trees, and further advances must depend on the new clones when they begin to bear.

The Future.

The second phase of the Cacao Research Scheme must evidently be one of consolidation. In the first place, selected trees have to be tested by the behaviour of their progenies, both by seedling reproduction and by vegetative propagation. Seedling progenies must be set out on various soils, to give general information about the inheritance of yielding power. In the case of the vegetative progenies, the comparisons are to be made statistically on one site, and preparations are being advanced for the propagation and planting of 10,000 trees in the most elaborate field experiment ever laid out with cacao. The objects of this experiment are numerous. Each selection will be represented by 100 trees, and

comparisons will be possible of agricultural behaviour, time of bearing, resistance to diseases and so on, as well as of yield and quality of product. Concurrently there must be comparisons of the various methods of vegetative propagation now possible, viz.: fan cuttings, chupon cuttings, fan buds on seedling stocks, and chupon buds on seedling stocks. There must also be trials and comparisons of the trees selected as clonal stocks.

With all these experiments ahead, work in the current year (1936) is being restricted almost entirely to propagation, and especially to the completion of the nurseries from which material must be drawn. It may be anticipated that for several years the laying down of field trials will be the main preoccupation of the staff.

There is, however, another line that must be pursued as opportunity offers in the next few years. The time has arrived, now that the pressure of the preliminary period is over, to form a botanical collection of cacao types and nearly related forms from countries outside Trinidad. The range of variation in Trinidad is the widest in any equivalent area in the world, but it does not cover the whole range of the crop. In anticipation of future requirements, as research pushes deeper into the problems of cocoa production, it is most desirable that there should be somewhere within the Empire a truly representative collection of trees, among which the cacao breeders of the future may find the raw material of new varieties. Not yield alone nor quality alone has to be studied, but resistance to pests and diseases, and adaptation to various ecological conditions. These may be found in the most unlikely commercial types or even in related species, and until a collection is formed botanists working on cacao problems will always be working largely in the dark.

Acknowledgments.

It must be recorded with regret that the botanists who have been responsible for the preliminary researches of 1930-35, Dr. F. J. Pound and Mr. E. E. Pyke, are no longer associated with the Cacao Research Scheme. The position reached is due entirely to their efforts, and the foundation they have laid for their successors is a solid one.

Thanks are due to several contributors to the Scheme for constructive criticisms which have strengthened the programme, to the Department of Agriculture, Trinidad and Tobago, for assistance in many ways, and by no means least to the cacao planters of the Colony for their continued co-operation in those researches which could not have been carried on without their help.

THE VEGETATIVE PROPAGATION OF CACAO.

VI.—General Notes on Technique with Cuttings.

By E. E. Cheesman and G. E. L. Spencer.

When in 1933 Pyke (*Second Ann. Rept. Cacao Research* (1932) pp. 5-9) reported up to 90 per cent. successes in rooting semi-hardwood cuttings of cacao, the technique might be said to have been established, and there have indeed been no radical changes during the last three years in the methods described by him. It was to be expected, however, that experience of the process in routine operation would lead gradually to slight modifications, each unimportant in itself but together tending to a marked improvement in the constancy of results. This has occurred, and without supposing that finality has been reached, we believe that a detailed account of the procedure actually being followed at the end of 1935 will have its usefulness.

Material.

The cuttings being used at present are almost exclusively taken from young budlings growing in special nurseries. This is partly a matter of convenience, but for propagation on any large scale it may be considered a necessity. Cuttings taken direct from bearing trees in the field root very well if the tree is well situated and if it is in exactly the right condition of foliage, which occurs immediately after the first hardening of the young leaves from a new flush. They remain in the best condition for only a few days, and in collecting from estates at a distance from the nurseries it is rarely, and then only by chance, that material is found in the ideal stage. Even then it is doubtful whether results can be obtained as good as those from nursery plants; there seem to be advantages inherent in cuttings from young, non-bearing trees, possibly connected with a lower carbohydrate/nitrogen ratio, though this is speculation.

Budwood can almost always be obtained from any healthy tree, and it has proved convenient to take that, rather than cuttings, in the first place. Since we wish to study both "fan" and "chupon" cuttings, budwood of both types is taken if available, but as a general rule only fan shoots can be had, and chupons have to be obtained later by manipulation in the nurseries. Assuming that only fan buds are taken, the complete process is as follows:—

(1) Using the "patch" method (*4th Ann. Rept.* pp. 3-7), 10 to 20 buds are put on seedling stocks, about six months old and spaced at three by three feet in a shaded nursery, where the shade is under control.

PLATE I.

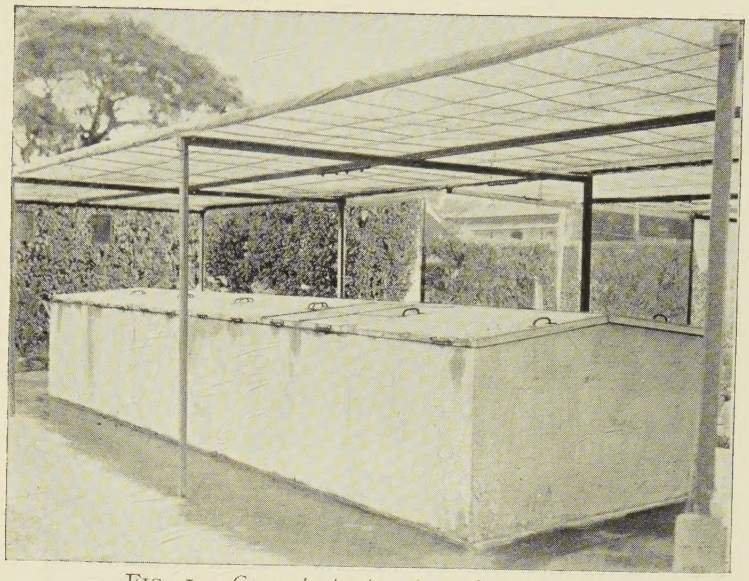

FIG. 1.—*Concrete propagator, of twelve bins.*

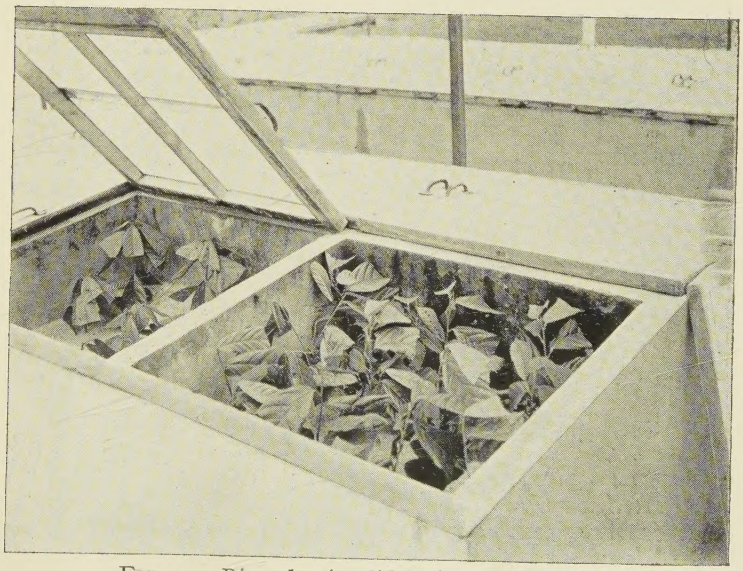

FIG. 2.—*Bins showing lids raised and removed.*

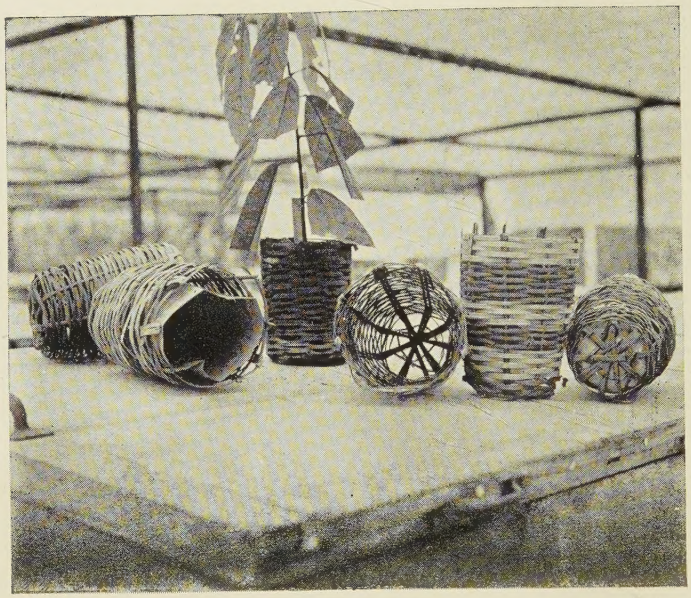

FIG. 3.—*Planting baskets.*

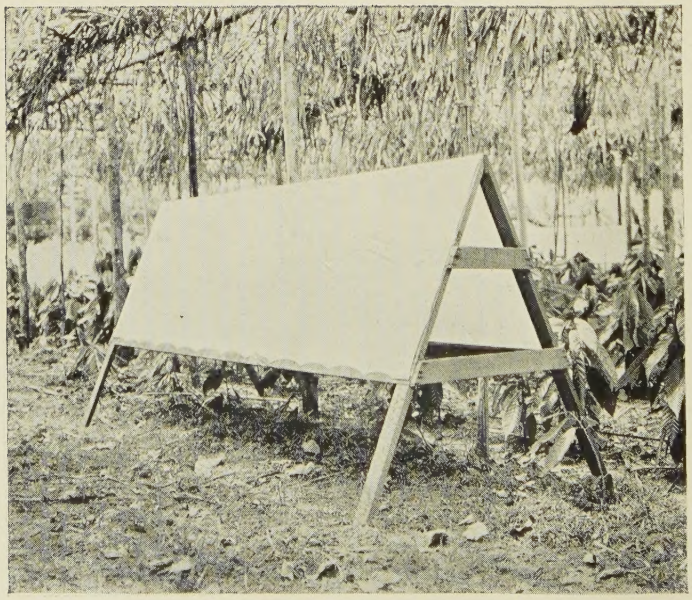

FIG. 4.—*Portable canvas shade.*

(2) Shoots can usually be taken as cuttings at about four to six months old, but if several are required from each budling it is desirable to let them grow larger and branch. A budling at a year old will yield at least half a dozen good shoots.

(3) After sufficient fan material has been taken, the budlings are cut hard back, leaving only a few leaves or a single lateral branch. If no foliage is left, the plants sometimes die, especially in very wet or very dry weather.

(4) In due course buds will shoot from the stub, and it is most likely that from ten plants treated at least two or three will produce chupons. Usually more will do so. Occasionally it may be necessary to cut back a second time a few months later, before chupons appear.

(5) Each chupon, decapitated, will produce three or four more from its axillary buds, and a good supply of chupon material is soon built up. The rate of multiplication may be increased when necessary, by using the first formed chupons as budwood rather than as cuttings.

The actual time occupied from first to last depends obviously on the number of buds originally taken, and on the number of cuttings finally required. If speed is essential and plenty of stocks are available, fan cuttings can be established on their own roots in about six months from the collection of budwood. Production of chupons cannot be unduly hurried by any methods yet discovered, and budlings cut back too young often fail to make any, but they should be forthcoming within a year.

Where continuous supplies of cuttings are required, as in our own work, it is probably best to make new nurseries with the first cuttings rooted, and to destroy the original budlings. We have done this, in order to reduce risks of error from the springing of shoots on the seedling stocks. The life of a cutting kept pruned by the continual removal of shoots for propagation cannot yet be stated, but nurseries may be expected to last several years if carefully treated.

The Propagators.

The type of propagator now used, as the outcome of experience, is essentially a concrete bin three feet long by two feet six inches, with a slightly sloping lid, the back being three feet above ground level and the front two feet ten inches. The height is determined solely by convenience in setting the cuttings. The sand bed, six inches deep, is raised to a minimum of one foot from the lid by filling the bottom of the bin with large stones and gravel. A drainage hole is provided, at the bottom. For economy of construction the bins are built in banks of 12, arranged back to back in two rows of six. (Plate I, fig. 1.)

The lids are glazed, but we have made trials with a calico-covered frame which gave good results, and the use of glass is certainly not essential. The fabric lid has the advantage of being much lighter in weight than the glass lid, not only on account of the fabric itself, but because the supporting wooden frame can be made much lighter. The calico develops moulds after a time and needs renewal.

The lids are not hinged, but are provided with handles on the top as well as at the front, so that they can easily be lifted right off the bin (Plate I, fig. 2).

The bins are covered with a canopy of light angle-iron and stout wire, which should ideally project at the sides and ends sufficiently to shade the bins at all hours of the day and all seasons of the year. It saves space, however, to reduce the overhang and use side-curtains east and west to cut off morning and evening sun. The top, like the curtains, is of calico, which seems to give just the right amount of shade. Palm leaves and alternate strips of roofing felt and a glass substitute have been tried, the former giving too dense a shade beside harbouring vermin, the latter proving too expensive in renewals.

The glass lids are now covered with a double layer of cheesecloth, which combined with the calico shade does not cut off too much light. This is kept wet during the day, and evaporation from it cools the interior of the propagator by as much as 5-6°C with evident benefit to the cuttings. This is the only measure taken to control temperature in any way.

The coarse calcareous sand used since 1931 has consistently given better results than any of several other rooting media tried. Much of the original sand is still in service, and does not seem to deteriorate in any way from constant use. Moss rarely grows on it, and only when it remains undisturbed longer than the average rooting requires.

Watering is done three times a day, and owing to the excellent drainage can scarcely be overdone. Either a can or a hose with a fine rose can be used.

Setting Cuttings.

Fan shoots root more quickly than chupons, and have given 100 per cent. in three weeks. Potting is done once a week, and very few are usually left after the fourth week. Chupons may take anything up to 12 weeks, and experiments in means of hastening them are proceeding. Ringing and wiring have already been tried, but their effects are if anything adverse, as they seem if not actually to retard rooting to lessen the volume of roots produced in a given time.

Almost the only serious setbacks experienced lately have been attacks of thrips. Thrips seemingly breed in the bins, and if only a few are introduced, on material apparently quite clean they bring about yellowing and abscission of the leaves before rooting can take place. To control them all cuttings are now washed before setting in a solution containing nicotine ("Black leaf 40" 1 : 500) with a trace of soap, and when raised for potting they are treated again in the same way. This is a preventive measure, and is of no avail

to save material already heavily attacked. A cutting badly infested before setting usually loses its leaves in the propagator, and even if it retains a few and forms roots will lose the remaining leaves before a new flush develops. No fan cutting completely defoliated in this manner has ever yet been observed to survive.

A yellowing of the leaves along the veins, followed by abscission, is sometimes found during the dry season, and is attributed tentatively to water shortage in the cutting at the time of collection. On dry days, even in the wet season, a bucket of water is taken into the nursery and cuttings are placed in it instantly as severed. It might be even better to cut under water, but this is scarcely feasible. Prompt transference to the water on severing seems sufficient to minimise the drawing of air into the vessels that undoubtedly takes place when a transpiring shoot is cut. The further precaution of collecting cuttings in the morning, while their negative pressure is still low, is adopted.

The cutting off of the apical half of each leaf when setting cuttings in the bins was originally suggested as a means of reducing transpiration. The method has been retained because it saves space in the propagator. Cuttings are set about $4\frac{1}{2}$ inches deep.

Potting.

Rooted cuttings are potted off into loosely woven baskets of about the same capacity as a six-inch pot*. These baskets are locally made of " tirite " (*Ischnosiphon Arouma*). (Plate II, fig. 3). It is convenient in filling them to line them with paper, which quickly rots away. The potting mixture is made up of two parts loam, one part sifted cow dung and one part of coarse sand, the same as that used in the bins. The baskets are placed in an empty propagating bin, and the lid kept closed until roots appear through the sides, which may be within a week or may be longer.

* Similar baskets are used in the Botanic Gardens in Georgetown, British Guiana, and we are indebted to Prof. J. S. Dash and Mr. E. B. Martyn for specimens and details of their construction.

Planting.

As soon as the roots come through the baskets indicating that a certain minimum root system has been established, the plants may be set out in the field nursery. No special hardening off is required, because as a rule the root system is well grown before any new growth is made by the shoot. The only leaves on the rooted cutting, therefore, are the remaining basal halves of leaves which originally developed in the open air and these are already hardened. Reasonable precautions must naturally be taken against exposure to direct sunlight or wind, and against drying of the compost in the basket, until the cuttings are well established in their outdoor environment.

It may occasionally happen, especially if the cuttings are rather too woody in the first place, that a new flush is developed before roots show through. Such plants are removed from the closed bins at the first signs of flush and given as much light and air as they will tolerate, so that the flush develops sturdily. The need for a true hardening off, as in these cases, is abnormal.

In planting, the basket is set in the ground to about half its depth. It is found that in spite of every care that can be taken the contents will always sink in a few weeks, sometimes as much as two or three inches. The reason is without doubt the impossibility of packing a rather stiff soil round the baskets without leaving air spaces due to the weave of the baskets themselves. As the " tirite " rots, these spaces collapse and the light compost sinks into them. To counteract the sinking, the baskets are originally planted so that the roots inside are at, or even above, the soil level outside. In the nursery, which has been well tilled, it is not necessary to dig large planting holes, but in planting at stake in the field it will no doubt be necessary to plant on a mound in the usual way, and still to set only the bottom of the basket in the soil.

The nurseries are under living shade, but it is often desirable to supplement it for the first few days after planting. For this purpose light frames of wood covered with calico are used, and the most convenient pattern is a span-roof type (Plate II, fig. 4).

PLATE III.

FIG. 1.—*Root system of a cacao seedling, 5 years old.*

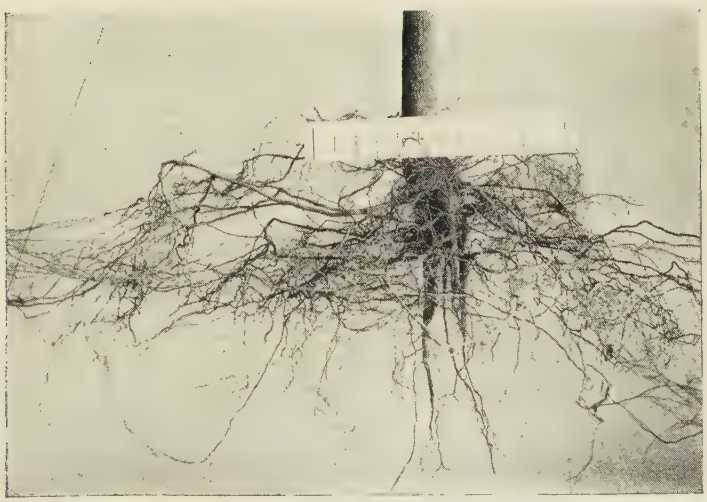

FIG. 2.—*Root system of a chupon cutting, 2 to 2½ years old.*

FIG. 3.—*Root system of a fan cutting, 2 to 2½ years old.*

THE VEGETATIVE PROPAGATION OF CACAO.

VII.—Root Systems of Cuttings.

By E. E. Cheesman.

A number of cuttings, some chupons and some fans, which were planted out towards the end of 1933, have been raised for examination of their root-systems. There were in the same plot a number of five-year-old seedlings, of which one was raised for comparison because there were no 2 to 2½ year seedlings available in exactly similar soil. Several cuttings of each type were excavated, and one of each has been photographed together with the seedling (Plates III & IV figs. 1-3).

The photographs speak for themselves, and there is little comment to be made. The seedling has a surface system of fibrous roots, and a descending taproot, and the cuttings repeat the arrangement on the smaller scale appropriate to their age. Instead of the true taproot of the seedling they send down two or three vertical roots. The dense mass of fibrous roots near the stem in the case of the fan cutting photographed is accounted for by the rich compost in which it was originally potted. In the case of the seedling only half the root system is shown, as only half was excavated.

It is interesting to note that the initial differences noted by Pyke (*3rd Ann. Rept.* pp. 4-6) in the rooting behaviour of fans and chupons have not persisted, and taking into account all the cuttings examined it would be impossible to say from the underground systems alone which type of cutting had been used in each case.

The soil in which these plants were growing is a sandy loam. The excavations were performed by Mr. C. W. R. McCreary, to whom my thanks are due for his painstaking efforts.

THE COMPLETION OF SELECTION, 1935.

By F. J. Pound.

In the Second and Third Annual Reports descriptions have been given of 36 trees out of 100 which have been selected for high yield, coupled with good quality as shown by size of bean, and are to be further studied by field trials of their progeny.

The 64 descriptions remaining are presented here, and with their appearance the selection programme, so far as it concerns the Trinitario population of Trinidad cacao fields, is for the present closed.

I.C.S. 23.

This is a small tree occurring in a heavy alluvial soil on the edge of a ravine which frequently floods. When it does flood the tree is generally completely waterlogged for days on end and often half submerged for hours. It is on account of this fact that the yield is somewhat erratic. During the setting season the tree appears to send out new fruit following the complete loss which occurs at each submergence. Often, however, only 35 to 40 pull through in the course of a year which is less than the required 50 to 60 judged from the size of the tree. For this reason the description was withheld from two earlier reports but now it is felt that the poor crop in some years is due entirely to accidents.

The pods are very fine, oval in shape and measuring as much as 10 inches by 5 inches. They are rather heavily pigmented, with green in the furrows. The shell is thin and somewhat warty. There is no long-pointed apex or bottle neck.

The beans are purple but plump averaging about 36 per pod and weighing about 180 gms. Thus pods and beans are well up to standard and the bearing would be entirely satisfactory were the tree growing in a more favourable situation.

I.C.S. 34.

This tree was at one time a very large one noted for its outstanding bearing capacity and fine pods. It is growing in a clay alluvial soil which is very subject to flooding. A few years ago it was blown over and at the present time only a large water-shoot remains. The pods are somewhat short, oval, unpigmented and rather smooth. In size they rarely exceed 7 inches in length and 4 inches in breadth. The shell is moderately thin. Only a few pods have been tested because the chupon has not yet come into full bearing. In these the beans are all purple and lozenge shaped, usually more than 40 to the pod; from the pods tested to date none has given less than 200 gms. of wet cacao. Since the evidence of high bearing of the original tree is authentic and the pods on the chupon average probably less than 6 to the pound the tree is considered worthy of trial among the 100 to be selected.

I.C.S. 35.

This is a tree of about 15 to 20 years of age situated in the middle of a recently drained swamp. The soil is a sandy alluvium and is deep and fertile. The tree was noticed as a heavy bearer several years ago when a sample of pods was tested. Beans averaged 40 to 45 per pod and wet cacao 170 to 200 gms. The pods average about 6 to the pound of dry cacao. They are

very dark red in colour, long oval, not deeply furrowed and only slightly warty. There is no obvious neck constriction and no pronounced point. The shell is of medium thickness. The tree occupies a planting space of not more than 14×14 ft. and in 1934-35, the first year crop was recorded, the yield was 99 pods. For the crop year 1935-36 no pods had been picked up to the end of December but it was holding 50 to 60 large pods, some 40 to 50 large cherelles, and a mass of smaller ones, some of which will not survive.

I.C.S. 36.

Like I.C.S. 35 this is a comparatively young tree which is probably a seedling of Nicaraguan ancestry. It occurs on an alluvial soil on a fairly steep slope. The soil is probably comparatively fertile as several trees around are good bearers. The pods are not exceptionally large, the shell is moderate in thickness and the beans average between 36 and 40 per pod. The wet cacao is rather variable, some pods giving over 200 gms. and others as little as 120 gms. The average is approximately 160 gms. or seven pods per lb. of dry cacao.

Pods are white with no pigment, measuring about 8 inches by 4 inches. There is a slight bottle neck but no pronounced point. The surface is delicately warty, furrows not deep.

During the crop year 1934-35 the tree produced 148 pods and for the current crop it has a fair showing of pods. The space occupied by the tree is about 18×18 ft.

I.C.S. 37.

This tree is also a seedling from a tree selected about 20 years ago as a heavy bearer of large beans. The parent unfortunately has been lost. Growing on an alluvial slope of what looks to be a relatively free draining and fertile soil the tree occupies a little more than 12×12 ft. It has been noticed as a continuous bearer for several years and it was not until the crop was actually recorded that the amount of cacao produced per annum was realised. During the 1934-35 crop 126 pods were actually picked from the tree. This crop is much in excess of what would be required from a tree of this size but allowances must be made for its favourable situation, lack of crowding by neighbouring trees and efficient shaping. As in I.C.S. 36 the wet cacao per pod is rather variable, the larger pods tested gave 48 beans weighing 240 to 260 gms. while the smaller pods gave about 30 beans weighing 150 gms. The interesting feature is the size of individual beans even in the small pods. The pods are rather longer than those of I.C.S. 36, measuring about 10 inches by 4 inches. There is a well pronounced bottle neck but no long point. The pod is partially pigmented on a white base and warty. The shell is rather thinner than average.

I.C.S. 38.

This is a very young tree, not more than 8 years old growing in a rich loam pocket of soil, well drained and not heavily shaded.

In type the tree has a pod which very closely resembles *Theobroma pentagona* with very pronounced bulges. The shell like that of *Theobroma pentagona* is very thin. The pods are partially pigmented on green and rather small. The beans are large and purple.

The interest in the tree lies not so much in its type as in its heavy bearing and absence of black pods. This latter feature was the first thing pointed out by the owner who stated that he had never picked a diseased pod from the tree whereas *Theobroma pentagona* generally is very susceptible to blackening. The tree is very vigorous and during one year has grown from a 10×10 ft. space to a 12×12 ft. space. For two years (1933-34 and 1934-35) it produced more than 50 pods per annum and for 1935-36 it is laden with pods of all sizes. Several pods tested at random gave an average of 31 beans and 153 gms. of wet cacao. The beans therefore are well over standard. Further pods are being tested.

I.C.S. 39.

I.C.S. numbers 39, 40, 41 and 42 represent trees grown by a peasant on a deep loamy but very steep slope of apparently fertile soil. The origin of the acre block of trees from which these four were selected is interesting. The seeds were taken from a tree which was probably one of a number of introductions from Nicaragua some 20 to 30 years ago. The majority of trees in the block have pods much of the same type, unpigmented and generally of Nicaraguan Criollo shape but much longer and with large beans whose cotyledons vary from almost pure white to dark purple in colour. I.C.S. 39 is one of the best bearers in the block, occupying a space of 18×18 ft. and usually produces two distinct crops of 60 to 70 pods per annum. The pods are green unpigmented, long and warty (often measuring 1 ft. in length) with a slight bottle neck and a very pronounced point.

All the pods tested to date have given more than 200 gms. of wet cacao each, some exceeding 250 gms. The number of beans averages, from 40 to 45 and in several pods beans weighing over 6 gms. were found. All beans are exceptionally plump.

I.C.S. 40.

This is a tree growing close to I.C.S. 39 and was noticed by the owner as a better bearer than the average. The space it occupies is only 12×12 ft. and the yield during 1934-35 was over 50 pods. For the 1935-36 crop there were in January 40 pods and a large number of younger fruit.

The pods are green without pigment, square shouldered, with a long pointed apex, and warty surface. The shell wall is rather thicker than average.

Only a few pods have been tested and none has given less than 200 gms. of wet cacao. The beans vary from 38 to more than 40 per pod and are very plump. On the assumption that less than 6 pods from this tree would give one pound of dry cacao, the yield should be 8 lb. of very fine beans.

I.C.S. 41.

This tree is growing in a moist ravine in deep loamy soil and has grown to occupy a space of 17×17 ft. It has been marked by the owner for several years as a good bearing tree and for the 1934-35 crop produced more than 100 pods. The majority of these were checked by inspectors. For the May crop 1936 there remain 30 to 40 pods, twenty having been picked during January as the tail end of a large December crop.

The pods are long oval and warty with a very well defined point and splashed with red on a green base. They average 9 to 11 inches in length and 4 inches in diameter. The bean number appears to be relatively constant but low, rarely exceeding 36 per pod. The individual beans, however, often exceed 6 gms. in weight and the pods tested averaged less than 6 per lb. of dry cacao.

I.C.S. 42.

This tree occupies a space of 17×16 ft. on the same soil type as the three previous selections and on account of its heavy bearing has been used as parent for supplying missing trees in the cultivation. The pod type is much like those described from the same block, long oval, with well pronounced point, warty surface and shell of medium thickness.

During the calendar year 1935 the owner recorded 100 pods from the tree, 30 were harvested during January, 1936, leaving 35 mature and some 25 to 30 large cherelles for the May crop.

The pods tested gave an almost constant number of 40 beans each and wet cacao ranging from 180 gms. for small pods to 240 gms. for large pods. Hence the beans and pods are well up to our selection standards.

I.C.S. 43.

This tree is growing somewhat isolated on a flat sandy loam soil. It is quite a young tree now occupying a space of 14×14 ft. having grown vigorously during the last two years.

For the year ending May, 1935, 100-110 pods were picked, 60 of which taken at random gave the following average: 38.5 beans; 163 gms. wet cacao.

Individual pods often contain more than 225 gms. of wet cacao but pods at the tips of the branches tend to be small. For the 1935-36 crop nearly 100 pods have been reaped and 28 mature pods remain to be picked in addition to a number of young fruit which may mature before 1st June, 1936. Although some branch pods fall below standard there is such an excess over the number required that the tree yields its quota of pods at 6 to the pound leaving 30 to 40 smaller ones as bonus.

The pods are long, oval and unpigmented with a somewhat square shoulder and prominent point. It was noticed by the owner that many of the pods give seeds which on germination prove to have white or almost white cotyledons, denoting very high quality in addition to vigour and high bearing.

I.C.S. 44.

This tree is growing on a well drained gravelly loam soil of rather high fertility. Two years ago the overseer in looking for good trees noticed it was a good bearer but the pods were not tested. When brought to our notice it was spanning 18×18 ft. and holding 97 mature and ripe pods besides 50 to 60 cherelles of varying sizes while no other tree around was bearing heavily. The overseer states that exactly the same occurred during each of the last two years.

The pods were not exceptionally large, measuring on the average approximately 6×3½ inches, but hung on the tree in clusters of 2 and 3 per cushion. One from a cushion containing 4 pods gave 36 beans weighing 190 gms. The average for the ripe pods on the tree at the end of January was 40 beans weighing about 160 to 170 gms.

The shell is thin, slightly warty and partially pigmented on a green base.

I.C.S. 45.

This tree is growing in a sandy loam soil and was noticed at the commencement of selection work to have large pods and large beans, some of which gave a pale break. For two years it produced slightly fewer than the required number of pods for selection occupying as it did at the time some 16×16 ft. In 1934 the field in which it occurred came in for heavy pruning and the trees around I.C.S. 45 were very heavily trimmed back. I.C.S. 45 itself was pruned to occupy but 14×14 ft., put out copious new growth and in 1934-35 produced over 50 pods. The crop for 1935-36 will exceed 100 pods for although crop in that field is somewhat late the tree was holding 90 half grown and ripe pods and a large number of younger fruit.

The pods are unpigmented, long and oval, somewhat warty and with obvious Criollo connections. They measure 9 to 10 inches long and 4 inches in diameter. The beans are exceedingly plump averaging 36 to 40 per pod and pod value averages 6 to the pound.

This tree has been included in the list on account of its splendid response to pruning helped by more light and air around.

I.C.S. 46.

I.C.S. numbers 46, 47, 48 and 49 appear to have the same origin as Nos. 39 to 42 for three of them show very obvious signs of Nicaraguan ancestry.

They all occur in a half acre block only a few feet above sea level. The soil is almost black and sandy in texture and the block probably gets a good deal of refuse washed from dwellings

nearby and pen manure from animals tethered there. Nevertheless the leaves on the trees show very bad leaf edge browning usually associated with severe deficiency of potash in the soil. This has yet to be tested. The rough yields gathered in 1933 showed up the best bearing trees and accurate figures were kept for the best of these during 1935.

I.C.S. 46 occupies a space of 12×11 ft. and produced 54 pods between May, 1935 and December. It was holding a crop of 47 to be picked before March, 1936 which is almost the total yield required for 1936.

The pods are unpigmented, somewhat square-shouldered with a long warty point. The shell is moderately thin. Only a few pods have been tested and these averaged 33 beans weighing 150 gms. Thus although the wet cacao is only on the borderline of our selection standards the beans are well above and the yield is excellent.

I.C.S. 47.

This tree very closely resembles I.C.S. 46 in type and spans a 12×12 ft. planting space moderately well. During 1935 it produced 60 pods and is now holding 30 for the May crop, 1936. The pods average 40 to 43 beans weighing 160 to 180 gms.

I.C.S. 48.

This is probably a sib of 46 and 47 and is of similar type. It barely occupies as wide a space as 12×12 ft. and was recorded as producing well over 50 pods for the 1933-34 crop. The 1934-35 crop gave between 50 and 60 pods and it is holding 35 large pods to be picked before May, 1936.

The beans are not exceptionally large. They average 40 per pod and 160 gms. of wet cacao.

I.C.S. 49.

Although this tree is probably a sib of the three previous selections it is smaller and bears pods of an entirely different type. Occupying a space of 10×10 ft. it produced a heavy unrecorded crop for 1934-35, 24 pods for the December, 1935 crop and holds 30 for the April-May crop, many of which will be harvested before that date. The beans average 40 per pod and 170 to 180 gms. wet cacao.

The pod type is pigmented with green furrows, long oval, slightly warty, measuring 9×4½ inches.

I.C.S. 50.

This is a large tree spanning 20×20 ft. on a flat site which is liable to flooding with heavy rains. The soil is a heavy alluvial clay but well drained by deeply dug drains. The tree has been used for supplies for a number of years and is outstanding in bearing capacity compared with its neighbours. The average annual crop has been recorded as 150 pods.

The pods are oval and unpigmented, shell moderate to thin, surface relatively smooth, size 7×4 inches.

In those tested the beans varied from 36 to 43 and wet cacao averaged 170 to 180 gms.

I.C.S. 51.

This tree occurs on the same soil type as I.C.S. 50 but about two miles away. It is a large tree spanning 18 to 20 ft., known for several years to be a heavy bearer, and recorded for two years at approximately 200 pods per annum.

The pods are dark red in colour, oval in shape, shell moderately thin, smooth. The beans and wet cacao are similar to those of I.C.S. 50. In both cases the beans are lozenge-shaped.

I.C.S. 52.

This is a low spreading tree growing on a heavy clay soil known to be deficient in phosphates. It spans about 15 ft. and during the last three years has produced an average of 85 pods per annums It is recognised as a hardy type which bears pod. every year even when the crop in the locality is poor.

The pods are deeply pigmented, long oval, and not obviously warty. The shell is thinner than average and the pods average 41 beans, and 6 pods to the pound of dry cacao. Many of the pods contain over 200 gms. of wet cacao.

I.C.S. 53.

This tree occurs on the same heavy clay soil type as the preceding example but is a much taller tree. The ground space which it occupies is about 18×18 ft. For the 1933-34 crop it produced more than 150 pods which was a relatively small crop for the tree according to the owner. The 1934-35 crop was not good on the estate generally but this tree matured 130 to 140 pods. The pods are heavily pigmented with a suspicion of bottle neck, slightly warty but with a moderately thin shell. The pods measure some 8 to 9 inches in length and 4 inches in diameter. The beans usually number 35 to 40 and wet cacao averages 175 gms. per pod.

This tree is the corner tree of the field in which it occurs, hence part of the good cropping may be due to the extra light and air which it receives.

I.C.S. 54.

This is another tree from a heavy clay soil. It is comparatively large, spanning 17 or 18 ft. Although records are only known for one year when it produced 125 pods it has been long known as a heavy bearer and has been used for seedling supplies. Pods are relatively small like I.C.S. 2, only slightly pigmented, but with a very thin delicately warty shell. The beans are large, rarely exceeding 36 but the wet cacao often weighs more than 200 gms. per pod. The smallest pod tested gave 28 beans weighing 150 gms. which demonstrate that even in the small branch pods the beans are large.

I.C.S. 55.

This is a young tree about 15 years old growing on a black marly clay, in a flat vega. It is one of a number of seedlings planted on the estate all of which came from selected parent trees.

The tree is small compared with its less productive neighbours, spanning a bare 12×12 ft. The pods are small measuring about 6 inches by 3½ inches, deeply pigmented, and smooth surfaced. The shell is thin.

Beans average 36 per pod and wet cacao 180 gms. which is equivalent to 6⅛ pods to the pound of dry cacao. The individual beans often exceed 5 gms. in weight which is well above our selection standards. During the 1933-34 crop the tree produced between 50 and 60 pods and in the 1934-35 crop more than 60 pods, with a good showing to date for the 1935-36 crop. The tree seems to be one of the very self compatible types.

I.C.S. 56.

This tree is a chupon probably from an original sib of I.C.S. 32. The pods are nearer the shape of true Nicaraguan Criollo than those of either I.C.S. 32 or I.C.S. 21. The tree is small, spanning barely 12×12 ft. effectively on the top of a very dry ridge of clay soil. In its present situation it does not appear well suited to the local conditions and remains self incompatible for long periods. It is usually late in setting crop which only in good years exceeds 50 pods. On the other hand the pods are exceedingly efficient. They are partially pigmented, with a high shoulder and pronounced point. The shell is warty and thin. The beans are few in number, often less than 30 per pod but no pod has yet been recorded with less than 150 gms. of wet cacao.

I.C.S. 57.

This is a small tree, probably a daughter of a heavy bearing but not necessarily large beaned tree, planted in 1927. It spans about 10×10 ft. on rich chocolate soil and was noted several years ago as promising. Recently all other trees in the field have been felled for replanting and this tree is growing well as a response to additional room.

The pods are long, red, slightly warty, very slightly bottle necked but without pronounced point. They measure 8×4 inches. Beans average about 40 per pod and wet cacao varies in weight from 140 to 240 gms.

I.C.S. 58.

This tree is again a seedling of a parent selected for general all round value. It is rather older than I.C.S. 57 and is growing in a rich sandy loam on the edge of a recently drained swamp. The tree spans about 16×16 ft. but owing to poor shaping the branches are long and thin with no side shoots. Consequently the effective space has been calculated at 12×12 ft. The tree is not an exceptionally heavy bearer having produced between 50 and 60 pods per annum for three years. The pods are long, oval, with a slight bottle neck slightly pigmented and warty. The shell is very thin. The beans usually number more than 40 per pod and wet cacao over 200 gms. The largest pod tested gave 49 beans weighing 310 gms.

I.C.S. 59.

This is a fairly large tree growing on chocolate soil. It has been recognised for several years by the manager of the estate as an exceptional bearer. Records were not taken until pods were tested during the last crop when it was found that the average pods easily passed the selection standards, many giving more than 200 gms. of wet cacao. Bean number is usually more than 36. The beans are somewhat lozenge shaped. During the 1934-35 crop the tree produced considerably more than 100 pods, for in January after several pickings had been made there were about 100 safe pods on the tree together with a number of large cherelles. The pods are partially pigmented, long, oval, with neither pronounced bottle neck nor pointed apex. The shell is moderately thin and not conspicuously warty.

I.C.S. 60.

The three selections, I.C.S. 60, 61 and 62 are again types which show some characters of Nicaraguan or Venezuelan Criollo and although they are not pure there is usually a percentage of white or almost white beans in the pods.

Unlike I.C.S. 39, 40, 41 and 42 which are of similar origin and growing on very fertile soil, these three, without windbreaks or overhead shade, often have to stand up to very extreme drought conditions and it is surprising that they present as healthy an appearance as they do. It is obvious, however, from their hard, dry appearance, the occasional drying of whole branches and the withering of pods when half mature, that they are suffering from their unfavourable situation.

I.C.S. 60 actually occupies a space of more than 12×12 ft. and is a strange mixture of young vigorous shoots and old decaying branches. The pods are large, slightly bottle necked, long, warty, with long pointed apex and no pigment, often growing to a length of 10 inches. In the well formed pods the beans usually number more than 40, weighing 200 to 250 gms. A considerable proportion of the pods from the branch ends produce less than 20 beans which reduces the average bean number from 30 pods taken at random to 34 per pod. The bean weight, however, remains high, the average from the 30 pods being 170 gms. or 5 gms. per bean. The tree produced 54 pods for its last crop and was known to produce between 40 and 60 per annum previously.

I.C.S. 61.

This tree is of similar type to the above, but with smaller pods and with Nicaraguan Criollo characters of high shoulder and point a little more obvious. It is a fan grafted tree of a seedling sib of I.C.S. 60, and is low growing and unshapely. The effective space occupied is judged as 12×12 ft. Unlike the preceding example the beans rarely exceed 30 per pod and the average from 30 pods at random is only 27. Throughout large and small pods the seed weight is relatively uniform at 4.5 gms. per bean. The recorded crop for

1934-35 was 73 pods and it was known to be a good bearer previously. Thus for the size of the tree the yield and bean weight are exceptionally good but the wet cacao weight falls a little below our required standards.

I.C.S. 62.

This tree differs from the other two selections in the same block in pod colour, which here is deep red. The pods are long pointed, deeply furrowed and warty, measuring about 8 inches in length. The shell is moderately thin. The tree is reputed to be a true example of " Caracas Red " but this is not certain. It occupies less than a complete 12×12 planting space and produced more than 30 pods for the past crop. The pods consistently produce less than 30 beans, the average from 20 being 28 per pod. The individual beans rarely fall short of 5 gms. each. The tree has been selected for further trial on account of its fine beans of good quality for the majority of them on cutting turn out to be pale or even pure white.

I.C.S. 63.

This is a very tall tree growing on a steep slope of the gravelly Northern Range. It occupies a space of approximately 16×16 ft. and produced over 70 pods during the 1934-35 crop season but the total crop was not recorded. The 1935-36 crop has been recorded as 102 pods. The pods are long oval in shape, usually bottle necked, and only slightly warty with 10 furrows. There is no pronounced point. Pods average about 8-9×4 inches. The shell is of average thickness. Very large pods are common on the trunk and those at the tips of the branches may be small. They are completely pigmented. Bean number averages 41 per pod and wet cacao approximately 190 gms.

I.C.S. 64.

This tree is growing in a black marly clay soil. It is much larger than normal and occupies the space of three trees effectively. During the 1934-35 crop 150 pods were recorded from December onwards. During the current crop which was exceptionally poor pods reaped plus pods on tree amount to 147. The pods are deep red in colour, smooth, rather short oval with a pronounced point but no bottle neck. The pod value averages 36 beans weighing 170 gms. Large pods with more than 40 beans give over 200 gms. of wet cacao. The smallest pod sampled gave 35 beans weighing 150 gms.

I.C.S. 65.

This tree occupies a planting space of 12×12 ft. on a sandy loam hillslope. In type it is not outstanding, the pods being oval, more or less smooth and not ridged, and rather deeply pigmented. The pods are not large, usually measuring about 6 inches in length. The shell is moderately thin. The fairly plump beans average about 40 per pod, and the wet cacao about 160 gms. For four years the tree has each year produced masses of cherelles many of which die but usually 60 to 90 survive as the annual crop. Ninety pods were produced in the last crop year when normal yields were much below average.

I.C.S. 66.

This tree is old and now consists of two lanky chupons each of which occupies approximately the space of one unit. The pods are unpigmented, broad in the centre, tapering to a sharp point at the apex. The beans are lozenge-shaped and average about 36 per pod. Wet cacao varies considerably. In the larger pods there may be well over 200 gms. but some of the small pods in the dry season fall short of 150 gms.

The tree is growing on fairly good Brasso sands. It has been a very heavy bearer if the masses of cushions on the trunks are any indication. During the last crop 96 pods were recorded. The previous crop was more than 100.

I.C.S. 67.

This tree is growing in a heavy clay soil, lacking in phosphates. It occupies a planting space of 12×12 ft. and has produced between 50 and 60 pods during each of the last two seasons both of which have been poor for the island. The pods are long and oval, heavily pigmented, not very warty, with shell of medium thickness. The pods tested gave beans ranging from 43 to 48 and wet cacao from 195 to 210 gms. This may be slightly above the true average as only a small sample was available.

I.C.S. 68.

This and several of the following examples are growing in a heavy clay soil like that of I.C.S. 67. The soil tends to be a mixture of marl in some places and green clay in others; both need phosphates according to their analysis but on green clay application of phosphates does not prove beneficial.

I.C.S. 68 occupies rather more than a 12×12 ft. space and although it would pass on an annual yield of 65 pods, produced 77 pods in the 1934-35 crop and over 50 during the present crop which was exceptionally poor. The pods are very dark in colour, warty with a long point and pronounced stalk-end constriction. The shell is relatively thin. The beans promise to be exceptionally large. In the largest pod tested 33 beans weighed 190 gms. and in the smallest pod ripe at the time 41 beans weighed 180 gms. The pods average slightly more than 6 to the pound.

I.C.S. 69.

This tree occupies a space of 15×15 ft. and produced 89 pods during the crop season 1934-35. It was very late in setting during the 1935-36 crop and at the end of the year was holding a large number of half mature pods with a promise of a fair crop. The pods are long and warty with a slight point and stalk-end constriction. They are completely unpigmented.

The bean number is fairly consistent, averaging 39 per pod. The wet cacao averages 185 gms. from the small sample of large and small pods tested.

I.C.S. 70.

This tree occupies a space of rather more than 14×14 ft. and requires a yield of 75 pods per annum to reach our selection standards. During the 1934-35 crop it produced 78 pods but owing to bad conditions it appears to be falling short of the required number for this crop.

The pods contain from 36 to 45 beans which vary considerably in size, one pod with 46 beans gave 225 gms. of wet cacao and another with 43 beans gave only 145 gms. of cacao. This large fluctuation may be reduced when the tree is growing in a locality where it is not flooded for half the year and dried out for the other half.

The pods are white with splashes of red pigment, long, oval in shape without long point or bottle neck. There are only 5 furrows in mature pods instead of the usual 10. The pods measure about 9×4 inches.

I.C.S. 71.

This is a rather larger tree than the previous example judged on space occupied. It consists of two trunks, probably chupons of an original tree, each of which occupies nearly a unit planting space. The pods are warty, rather small and oval with a suspicion of a bottle neck and a moderately thin shell. They are almost completely pigmented on a white base. The bean number is low, averaging only 32 per pod but the beans are relatively large, often weighing 6 to 7 gms. each. From the pods tested the wet cacao averaged 190 gms. which is equivalent to 6 pods to the pound. During the last crop 92 pods were reaped and a number in addition were eaten by squirrels so that for yield the tree appears to be up to standard.

I.C.S. 72.

This tree spans 14×14 ft. and like I.C.S. 71 is characterised by the same low bean number. The pods, however, are not as large, and require 7 to the pound or slightly more. The tree bore 80 pods during the 1934 crop, which is slightly in excess of requirement.

The pods are long, oval, warty and deeply furrowed, very dark red in colour measuring on an average about 9×5 inches.

I.C.S. 73.

This is a tree of little more than the average size growing in a heavy clay soil. The pods are long oval in shape and completely pigmented. There are only five normal furrows to the pods, and no pronounced point or bottle neck. The shell is moderately thick and smooth. For the 1934-35 crop 80 pods were recorded. During the current crop the number will be slightly less owing to general poor cropping of the district. Bean number averages less than 40 per pod and wet cacao 180 gms. Thus the individual beans are well up to the standard required.

I.C.S. 74.

This tree and the succeeding selection both occur close together in one field and are probably seedlings from the same original pod. I.C.S. 74 spans 14×14 ft. and was known by contractors as a good bearer. Sixty-nine pods were picked from the tree during the 1934 crop in addition to unrecorded pods taken by nearby contractors. Bean number varies from 30 to 35 and wet cacao from 160 to 180 gms. Thus the individual beans are very fine and the pods pass the standards for wet cacao. The pods are dark red in colour, long oval in shape, with well pronounced point and bottle neck. The shell is moderately thin, with 5 furrows, and only slightly warty.

I.C.S. 75.

This tree is rather larger than its sib above and is also constantly raided for pods by contractors. It spans 17×17 ft. and needed more than 100 pods to pass the bearing tests. Actually 87 were recorded in 1934 of which 80 were seen on the tree at one time. There is no doubt that well over 100 pods were actually produced. The pods are much better than those of I.C.S. 74 and contain an average of 40 beans giving more than 200 gms. of wet cacao. One pod tested gave 46 beans weighing 295 gms. while a pod picked from the end of a branch gave 39 beans weighing 205 gms. The pods are somewhat short oval and pointed, smooth and only splashed with red on a white base. They show no sign of bottleneck constriction.

I.C.S. 76.

This is a large tree growing on the edge of a small stream. The soil is composed of alluvial washings from the marly hills above and may be deficient in phosphates. The tree spans about 20×20 ft. and would require 160 pods to pass our test of bearing. Actually it produced 180 pods during the crop 1934-35, some of which in the dry season were very small but still with beans of fair size. The bean number per pod varied widely in the pods tested, the smallest pod having but 15 and the largest 39 beans. Wet cacao from the pods with more or less normal bean numbers averaged 160 gms. or seven pods to the pound. The pods are relatively small, not very warty, have no bottle neck or pronounced apex and are coloured dark red.

I.C.S. 77.

This tree is growing on a marly hillslope and spans 15×15 ft. It produced 88 pods during the 1934-35 crop with beans averaging 36 per pod and wet cacao 170 gms. After that it was pruned heavily and bore but few pods in the early crop of 1935-36.

The pods are white, unpigmented, long oval in shape and warty.

I.C.S. 78.

This tree occupies a space of 12×12 ft. and produced 65 pods during the 1934-35 crop. After that it was heavily pruned and missed the first half of the 1935-36 crop but was holding 48 large

pods for the second half. The pods are long, warty, and oval with a well pronounced bottle neck. The shell is of average thickness and white in colour with very faint flecks of red pigment.

Only a few pods were tested, in which the bean number averaged 36 and the wet cacao 165 gms.

I.C.S. 79.

This tree is rather larger than I.C.S. 78 and occupies a full 15×15 ft. span. It produced 77 pods during the last crop and was setting up a very heavy crop at the close of 1935. The pods are characterised by a low bean number, 33 as an average per pod, but the individual beans are larger than usual. The wet cacao averages 150 gms.

The pods are very dark red in colour, oval in shape and comparatively small. The shell is thin not very warty and there is no stalk end constriction to the pod.

I.C.S. 80.

This is another large tree spanning 14×15 ft. It produced 72 recorded pods in 1934 but one complete picking was missed by accident. The bean number is characteristically high being rarely less than 40 per pod and wet cacao in the pods tested average 190 gms. The pods are very dark red in colour, long oval in shape, with bottle-neck constriction but no very pronounced point. The tree was heavily pruned in 1935 and consequently checked but in December, 1935, was showing a very fine crop of young fruit.

I.C.S. 81.

This is another large and vigorous tree growing in a black marly clay soil. It occupies a space of about 18×18 ft. The pods are long oval and completely pigmented. There is no bottle neck or long point and only slight wartiness of the surface. The shell is moderately thin. Bean number is low in the pods tested, averaging only 34 per pod. The individual beans are large and plump averaging 5 gms. each, *i.e.* 170 gms. of wet cacao per pod. During the last two crops total pods recorded exceed 200 and several were missed in the 1934-35 crop prior to commencement of accurate records.

I.C.S. 82.

This tree is growing in a heavy marly clay soil and shows rather exceptional vegetative vigour as well as good cropping powers. It is a fairly large tree occupying a full 18×18 ft. and was pruned very heavily in 1933. Previous to this the tree had been producing about 100 pods per annum. The crop was reduced considerably for a couple of years after pruning. This may not have been entirely the effect of pruning for large numbers of cherelles were produced each year.

The pods are dark red, oval, warty and with a slight bottle neck. The shell is moderately thin and the beans are large and lozenge-shaped. The pods tested usually gave more than 40 beans and more than 200 gms. of wet cacao. The average would not be greater than 6 pods to the pound.

I.C.S. 83.

This is a tree spanning 16×16 ft. and growing in a gravelly schist soil known to be very deficient in potash. It consists of one straight trunk of about 20 ft. before branches occur and is characterised by masses of pods usually borne on the trunk during the early part of the crop season and on the branches during the later crop. Recorded for two years 1932-34 it produced approximately 100 pods per annum but in 1934-35 it produced the exceptional crop of 192 pods, some of which were naturally a little below selection standards.

The pods are warty, slightly bottle necked but with no very pronounced point. They are partially pigmented on a white base. The shell is rather thick. Beans average about 36 per pod. The range of wet cacao weight is large, some pods having as little as 100 gms. of cacao and others with more than 200 gms. This may be a feature of potash starvation for on experimental plots nearby where potash has been applied as a manure the dry season bean size has definitely improved.

I.C.S. 84.

This tree occurs but a few pickets away from I.C.S. 83 and is slightly larger. The habit of growth and bearing is much the same. According to the space occupied 160 pods per annum would be required to pass our efficiency standards. During the 1933-34 crop 150 pods were recorded during about three quarters of the crop season and 246 pods were picked during the 1934-35 crop. The pods are rather thick skinned, slightly bottle necked and almost completely pigmented. Beans average somewhat less than 40 to the pod and wet cacao 160 gms.

I.C.S. 85.

This tree is growing in a soil known to be very deficient in available potash and phosphate. It is planted in a spacing trial at 16×16 ft. and is now just occupying the full space at an age of 20 years. For a long period of years before it reached full size the crop averaged 63 pods per annum. The 1934-35 crop was 154 pods, the best annual yield to date. The pods are unpigmented and long oval in shape, slightly warty but with no pronounced bottle neck. Bean number ranges from 34 to 35 and wet cacao averages approximately 160 gms. or seven pods to the pound. The beans are inclined to be a little flat.

I.C.S. 86.

This is a relatively large tree growing in a sandy alluvium. It spans about 18×18 ft. The pods are partially pigmented on a white base, long oval, slightly bottle necked and rather warty. In size they vary considerably. The shell is of medium thickness. Beans average 35 to 36 per pod and wet cacao 155 gms. Some pods give more than 200 gms. of wet cacao. The beans are inclined to be flat in the smaller pods. During the three years that crop was recorded it has produced an average of more than 140 pods per annum and is thus

bearing slightly more than our minimum requirements. It is noticeable that the yields of this tree have remained relatively constant during the last three years when the yields of other trees have fluctuated considerably.

I.C.S. 87.

This is a tree growing in a medium loam soil and spanning about 17×17 ft. It is a tall tree probably about 30 years old. The pods are long and warty with both bottle neck and fairly well pronounced point. They are completely unpigmented. The shell is of medium thickness. The beans are large and plump rarely less than 40 to the pod and wet cacao probably averages more than 200 gms. per pod. Apart from the fact that the tree was known to be a good bearer the crop has only been recorded for the 1934-35 season when 152 pods were picked. This represents about 25 lb. of Superior Beans.

I.C.S. 88.

This tree is growing in a rather heavy clay loam and has been known as a heavy bearer for several years. Many supplies used to be taken from it for use on the estate. It is reputed to bear about 100 pods per annum but during the last two crops it has produced slightly fewer, in keeping with the very low average crops obtained from the same area due to adverse weather conditions. It occupies an effective space of about 14×14 ft. The pods are unpigmented and long oval in shape, slightly warty but with no pronounced bottle neck or long point. In pods tested the bean number varied from 28 in a pod at the tip of a branch to 43 from a pod on the trunk. The wet cacao from these pods was 155 and 215 gms. respectively. The average bean number is slightly less than 40 with wet cacao 180 gms. *i.e.*, $6\frac{1}{3}$ pods to the pound.

I.C.S. 89.

This tree is growing on a black marly clay soil on a gentle slope. It is a very large tree which has at some time fallen and produced a vigorous and heavy bearing chupon from the base. The original tree survived so that the effective space occupied is about 3 to 4 unit spaces. From December to May, 1935, 170 pods were recorded and in December, 1935 there was promise of a good crop while trees around were bare. The pods are unpigmented, green, long oval in shape, somewhat warty with shell of moderate thickness. Bean number seems to be lower than average varying between 30 and 40 per pod. Wet cacao in pods picked averaged 155 gms. Thus while beans are only just up to required standards, total cacao yield is good.

I.C.S. 90.

This is a small tree growing on a gravelly soil where many trees around have succumbed to root disease. The soil is notably poor and subject to extremes of moisture content. The present tree may be a chupon of an original which has been removed. It is occupying a space of barely 10×10 ft. and has produced between 30 and 40 pods for each of the three last crops. The pod shows clear signs of *Th. pentagona* ancestry in the pointed apex, wartiness of the surface and thin skin. It is only slightly pigmented. The beans are dark purple in colour, plump, and are the largest that have been found on the estate. There are rarely more than 32 to 36 beans per pod but on the average 6 pods will give 1 lb. of dry cacao.

I.C.S. 91.

This tree is growing in a heavy marly clay soil and is only about 15 years old. It occupies an effective space of about 8×10 ft. The pods are long, measuring about 9-10×4 inches, warty and pointed, with a slight bottle neck and completely pigmented. The shell is of medium thickness. The bean number is characteristically low being less than 35 in all the pods tested. Wet cacao consequently rarely exceeds 150 gms., our lower limit of selection, but the individual beans are well up to standard and very plump. During two years of recording it has produced 77 fruits, averaging 38 per annum.

I.C.S. 92.

This is another tree growing in a sandy alluvial soil. It occupies a space of 12×12 ft. and was first located in 1933. During the 1933-34 crop it produced more than 65 pods, and in the 1934-35 crop 81 pods were recorded. The pods are white, long oval, slightly bottle necked but with no pronounced point and no pigment. The shell is slightly warty and of average thickness. The mode of bean number is between 36 and 40 per pod and wet cacao 160 gms. There is a fairly large pod to pod variation. The soil is known to be deficient in plant foods especially potash and phosphate.

I.C.S. 93.

This tree is a seedling supply planted in 1927 from a selected parent and is thus about 9 years old. It commenced bearing in 1930 and in 1931 was noted as an outstanding tree both on account of the number of young fruit and the appearance of the pods. In 1932 a few pods were tested. The bean number varied around 36 to 40 and wet cacao ranged from 160 to 180 gms. During later years the beans have improved in size and plumpness. The pods measure about 8×$3\frac{1}{2}$ inches, the shell is thin. The pods are rather heavily pigmented, sometimes showing the green base on the underneath side, they have a curved point and bottle neck but are not very warty. During the 1934-35 crop when it was judged to be occupying a space of 10×10 ft. the tree produced more than 36 pods.

I.C.S. 94.

This is a large tree growing in a very bad gravelly soil where most of the neighbours have died out or are moribund. This tree has taken advantage of the decrease of competition around

and spread to occupy a full 24×24 ft. It was not located until some of the 1933-34 crop had been picked but nearly 200 pods were subsequently reaped from the tree. During the 1934-35 crop 304 pods were reaped. The pods are unpigmented, long oval in shape and slightly bottle necked. The beans are rather lozenge-shaped, averaging about 40 per pod ; wet cacao about 150 to 160 gms. The beans and pods are only just up to standard, but the bearing capacity is extremely fine for a tree growing in what proves for other trees to be a very poor situation.

I.C.S. 95.

This tree is growing in a sandy loam vega which is well watered by hill streams and occasionally waterlogged. The ground vegetation in spite of draining is luxuriant suggesting an unusually large proportion of nitrogen in the soil which according to manurial experiments should be detrimental to the cropping power of the trees. In the field about half a dozen trees stand out as much more efficient types than the remainder and I.C.S. 95 is probably the best of those. It spans only 14×14 ft. and thus would pass our selection test for bearing with a crop of 70 pods but when examined in March, 1936 was found to be holding nearly 100 half to mature pods and some 20 large cherelles. The pods themselves are probably only just up to selection standards for those tested averaged 150 gms. of wet cacao. The beans are plump and quite up to standard. The pods are very heavily pigmented, long oval in shape and not particularly warty. The shell is moderately thin.

I.C.S. 96.

This is a small tree spanning a distance of 10×10 ft. on a windswept hill-slope. The soil is a hard clay loam liable to drying out in the dry season. The tree is not very robust on its own roots but bears pods of exceptional value. There is some evidence that its origin is similar to that of I.C.S. 21 as the pods are similar in size and shape and are also unpigmented. Bean number is usually below 35 but the beans are very bold and usually pale in colour. Frequently pods with less than 35 beans give more than 200 gms. of wet cacao. The crop over two years has averaged slightly less than 40 pods per annum.

STUDIES OF FRUITFULNESS IN CACAO.

VIII. Second Year Observations in an Experiment Designed to Test the Gross Effects of Applications of Nitrogen, Potassium and Phosphorus on the Cacao Tree.

By F. J. Pound.

In the Third and Fourth Annual Reports on Cacao Research, descriptions were given of a manurial experiment conducted at River Estate with the object of deciding :—

(*a*) Whether the four by four Latin Square layout was a suitable design for manurial experiments on existing heterogenous cacao.

(*b*) Whether the plot size of 16 trees was large enough to give a relatively even mixture of trees when replicated four times.

(*c*) Whether the addition of certain inorganic manures, alone or in combination, would produce any noticeable effect on the components of final yield, or on the normal cycle of physiological processes in the tree leading to flushing, flowering, fruit-setting and so on.

Details of the layout, and natural yields over the experimental block for two years prior to manuring, were given in the Third Annual Report (pp. 28-32). The yields following the first year's application of fertilizers were discussed in the Fourth Annual Report (pp. 19-25). The conclusions drawn were as follows :—

(1) The four by four Latin Square layout is capable of demonstrating significant increases of yield of the order of 30 per cent. during the first year of application of manures. This applies to established cacao of the usual genetically heterogenous kind, provided that the trees are fairly uniform with respect to age.

(2) Soil heterogeneity may account for more than half the total sum of squares. 'Error' may vary from $\frac{1}{6}$ of the total variance up to as much as $\frac{1}{2}$. In all cases it is large.

(3) Precision may be increased fourfold by the use of previous records of a year in which the yields are highly and positively correlated with the yields of the experimental year.

(4) Potash improves the bearing especially in the presence of phosphates.

(5) There is some evidence that applications of potash improve bean weight as well as bearing capacity.

(6) No effect of manures on bean number can be traced.

(7) There seems to be a reduction of incidence of Black Pod disease when potash is applied without phosphate. Since there are no previous records of this character and susceptibility may be a genetic factor, the findings must be accepted with caution.

The second application of fertilisers was made in May of 1934 and in the present paper the effects on yields during the 1934-35 crop are discussed, both alone and in relation to the natural yield records of 1931-32. The effect of the fertilisers on tree physiology forms the subject of a separate paper.

Yield During 1931-32 Crop.

In discussing the value of natural yield records in the previous papers it was found that although previous records were taken both during 1931-32 and 1932-33 only those of the former year were of value in increasing the precision of judging the results obtained in the first experimental year. The reason was thought to be the generally abnormal crop during the season 1932-33. Accordingly the natural yields of the season 1931-32 have been selected to correct yields of all the experimental years and for this purpose are reproduced in Table 1.

Table 1.

Natural Yield Records, 1931-32 (Pods. Mean per Tree).

28	28	26	22	14	54	55	26
40	18	21	31	31	31	37	30
28	22	35	30	33	25	33	33
26	26	34	19	50	41	59	37

Hypothetical Treatment.	Total Pods.		Total.
	+ Phosphate.	− Phosphate.	
Nitrogen and Potash ..	984	1,136	2,120
Potash ..	1,168	912	2,080
Nitrogen ..	856	1,160	2,016
Control ..	952	1,016	1,968
Total ..	3,960	4,224	8,184

For the Analysis of Variance of yields for 1931-32 the reader is referred to the Fourth Annual Report on Cacao Research.

Yields During 1934-35 Crop.

(1) *Pods.*—The numbers of pods reaped during the second experimental season (1934-35) are set out in Table 2 as the mean number per tree for each half plot of the Square.

Table 2.

Mean Pods per Tree for Half Plots, 1934-35 Crop.

40	35	44	40	11	50	56	32
52	46	30	37	26	38	36	46
18	18	32	19	21	37	44	28
17	15	17	15	45	67	92	62

Hypothetical Treatment.	Total Pods.		Total.
	+ Phosphate.	− Phosphate.	
Nitrogen and Potash ..	1,402	1,198	2,600
Potash ..	1,773	1,382	3,155
Nitrogen ..	651	1,169	1,820
Control ..	840	922	1,762
Total ..	4,666	4,671	9,337

It will be noticed that although prior to applying manures *i.e.*, in 1931-32 the plots designed to receive potash were giving a slightly greater yield than the plots set aside at random as controls, the difference in yield between the same plots during the second season of treatment, is much more marked. There is no visible beneficial effect of nitrogen on pod yield and only a slight benefit from phosphate.

The Analysis of Variance of pods for the 1934-35 crop bears this out, potash alone showing significance.

Table 3 shows that the effect of Potash + Phosphate is much greater than the combined effects of Potash and Phosphate singly.

Table 3.

(Pod Yields Subtracted from Arbitrary Working Means).

	+ K	− K
+ P	+117	−94
− P	+ 43	− 20

Thus Sulphate of Potash alone at 2 lb. per tree appears to increase the yield of cacao trees significantly on River Estate at the rate of 4,313 pods per acre=50 per cent. Sulphate of Potash + Superphosphate of Lime together significantly increase the yield by 7,978 pods per acre=92.3 per cent.

The Use of Previous Records.

The Analysis of Variance becomes slightly modified when the yields of 1934-35 are statistically corrected by the natural yields of 1931-32. For considerations of space the analyses have been omitted. Table 4 shows the degree of relative precision which can be obtained by making use of the natural yield records.

Table 4.

Table of Relative Precision.

Year.	Variance.	Co-variance with 1934-35.	Vyx.	Relative Precision.
	Main Plot Units.			
1934-35	287	—	287	1.00
1931-32	77.2	140	39.6	8.70
	Sub Plot Units.			
1934-35	88	—	88	1.00
1931-32	137	79	46.4	2.07

Thus for Main Plot Units there is an increased precision of 8.7 times and for Sub Plot Units there is an increased precision of 2.07.

In the final analysis nitrogen appears to have had a significant effect in decreasing yield, taken over all plots where nitrogen was applied, although the four sub-plots treated with nitrogen alone gave a higher aggregate yield than the four sub-plots which received no manure whatsoever. This result is largely due to the depressing effect which nitrogen has on the benefits that come from application of potash in this experiment.

In the sub-plot section of the analysis the interaction of nitrogen with phosphate disappears for the same reason as it did in 1933-34*. The interaction of potash × phosphate remains significantly large.

(2) *Wet Cacao.*—There are no natural yield records by which the weights of wet cacao yields after manuring can be corrected for analysis. Hence the figures must be analysed as they stand. The total weight of wet cacao obtained per half plot for the 1934-35 crop is given in Table 5.

Table 5.

Weight of Wet Cacao in lbs., 1934-35.

65	52	65	71	10	78	84	50
76	75	46	58	35	59	59	72
37	27	45	19	34	54	74	50
35	21	30	14	63	71	122	98

Treatment.	+ Phosphate.	− Phosphate.	Total.
Nitrogen+Potash	243	236	479
Potash ..	323	271	594
Nitrogen ..	114¼	230	344¼
Control ..	176	160¼	336¼
Total ..	856¼	897¼	

It will be noticed that the lowest main plot treatment yield comes from the control plots and the highest from the potash plots. The highest sub-plot yield occurs in the case of potash+phosphate, and the lowest from the nitrogen+phosphate treatment.

The Analysis of Variance of wet cacao yields bears out the results obtained from the analysis of pod number as far as the effect of potash is concerned, except that the interaction of potash and phosphate although very high is not quite significant. The interaction of nitrogen and phosphate appears to be significant but since in the case of pods this significance was known to be due to accidents in layout it cannot be taken as truly significant. This proves the value of previous records in judging yield results given in experimental years.

Increases in Yield—1934-35—as a Result of Applying Fertilisers at River Estate.

(1) *The Increase due to Potash.*—In the absence of phosphate and nitrogen the increase in wet cacao of potash treated over control plots is 111 lb. for 32 trees (four sub-plots) = 69.4 per cent.

This is equivalent to an increase of 417 lb. of dry cacao per acre :—

Value at five cents per lb. ....$ 20.85

Potassium sulphate costs $56.00 per ton delivered at River Estate.

Cost of 600 lb. per acre.... ....$ 15.00

Thus allowing 25 cents per acre for applying the potash.

The Net profit per acre ....$ 5.60

(2) *The increase due to Potash and Phosphate.*—The four sub-plots given this treatment yielded 323 lb. of wet cacao, an increase of 163 lb. over the absolute control sub-plots (32 trees) = 102 per cent.

This is equivalent to an increased yield of 612 lb. dry cacao per acre valued at $30.60.

The cost of fertilisers works out as follows:

2 lb. potash per tree	....$ 15.00
2 lb. phosphate per tree	.... 6.16
Applying (calculated)	.... .30
Total	....$ 21.46 per acre.
Net profit per acre	....$ 9.14

The Effect on Incidence of Black Pod Disease (*Phytophthora palmivora* Butler).

The record of badly blackened pods resulting from attacks of *Phytophthora* has been taken during the 1934-35 crop as in 1933-34 with a view to discovering whether mineral deficiencies in the soil are predisposing factors to incidence or susceptibility of pods to disease. In 1933-34 potash appeared to have had a restraining effect on the incidence of the disease, which although not proving significant in the main treatment analysis proved significant in the interaction of potash with phosphate. Phosphate alone had no effect, but in combination with potash, destroyed the beneficial effect of the latter.

In Table 6 the Black Pods reaped in 1934-35 are given as a percentage of the total pods.

*4th *Ann. Rept. Cacao Res.*, p. 22.

Table 6.

Percentage of Black Pods, 1934-35.

9	24	14	11	17	11	15	18
21	13	14	16	15	8	13	14
12	33	26	33	6	19	14	8
12	28	20	30	11	20	21	18

Treatment.	+ Phosphate.	− Phosphate.	Total.
Nitrogen and Potash ..	72	44	116
Potash ..	82	51	133
Nitrogen ..	91	63	154
Control ..	58	93	151
Total ..	303	251	

Thus the absolute control plots show the greatest incidence of disease while the nitrogen+potash plots without phosphate show the least. Total potash treated plots show less infection than total non-potash treated plots but in every manured plot except the control, the phosphate treated halves show much more infection than the non-phosphate halves.

The Analysis of Variance for 1934-35 shows no significant differences due to Main Plot treatments but significant interactions between potash and phosphate.

The Analysis of Variance of Black Pod incidence for the two seasons combined proves that the effect of potash over the two years is to reduce the incidence of disease by a significant amount ($P=0.05$). Nitrogen has no effect whatsoever. In the case of the sub-plot treatment there is very nearly a significant increase of disease incidence resulting from the addition of phosphate. The interaction potash × phosphate is significant and would occur by chance less than once in 100 trials. This means that all the beneficial effect of potash without phosphate is annulled by the addition of phosphate.

This is the first time that it has been possible to demonstrate for cacao that by the addition of fertilisers, the trees change in susceptibility to disease. Whether the effect is concerned only with potash as such or whether it occurs because potash is the element limiting production on the site of the experiment remains to be tested.

It should be emphasised that the amounts of fertilisers applied were not based on any experience whatsoever of the quantities which would give best profits. The actual applications were intended to be heavy all round in order to emphasise interactions and the commercial results from balanced applications may be quite different. Thus it should be possible to evolve a mixture of potash and phosphate from which the beneficial effect of phosphate would be retained without its detrimental effects and still higher yields may be obtained as a result.

Summary.

The yields for the second experimental year of this experiment show that potash has again been largely responsible for the increased yields obtained.

Phosphate has been beneficial only in the presence of potash. Nitrogen has been of no apparent value.

The record of diseased pods shows that potash has also been associated with a reduction of disease incidence and phosphate with an increase.

Hence it is suggested that balanced applications of potash and phosphate might be given from which still further increases of yield may be obtained.

STUDIES OF FRUITFULNESS IN CACAO.

IX. Differences between High-bearing and Low-bearing Cacao Trees in Response to Inorganic Manures.

By F. J. Pound.

As reported by the writer in a previous publication (*Tropical Agriculture*, 9 (1932) 288-90) the natural yield records of a certain field at River Estate for the seven years 1921-28 disclosed on analysis a highly significant correlation (r = +0.97) between yield and variance in any given year.

This was interpreted as an indication that in favourable years the heavier bearing trees increase their yields above the average to a greater extent than the poorer bearers, thus widening the variation that is always present. A most interesting question that suggested itself in consequence was whether the application of manures would have an effect similar to that of a favourable season, or increase the yields of all trees alike, or perhaps even have the contrary effect of tending to level out the variation shown by unmanured trees.

Evidence in answer is obtainable from the manurial experiment in Field 8, River Estate that has been described in previous papers (*3rd Ann. Rept.*, p. 28; *4th Ann. Rept.*, p. 19; *5th Ann. Rept.*). Without repetition of descriptive details it may be recalled that natural yield records were kept in this field for the two crop seasons 1931-33, and that yield records for two crops under treatment (1933-35) are now available as well. For the purposes of this paper, the records of the trees that were relatively high yielders in 1931-33 before manuring have been separated from those of the relatively low yielders, and each class treated separately. Each sub-plot of eight trees has been considered as composed of four "high" yielders and four "low" yielders, the better four and the worse four respectively on the records of 1931-33. The division is necessarily in one sense arbitrary, but it serves its purpose of making a rough separation of the relatively good trees from the relatively bad, and the results of the analysis on these lines are of great interest.

The sub-plots which received no manures whatever gave yields in 1933-35, 16.2 per cent. higher than in 1931-33. To this the increased age of the trees may possible have contributed, but a two-year increment on 30-year old trees might be expected to be much smaller, if at all appreciable, and it is likely that the reason lay in better climatic conditions in the second period. This 16.2 per cent. increase was the resultant of a 17.1 per cent. increase on the part of the "high" trees and a 10.5 per cent. increase on the part of the "low". Here again is confirmation of the original finding, that good climatic conditions favour the heavy bearers more than the light. The really interesting point is that the unmanured trees are the only ones in the field to show this reaction; in every manured plot the "high" bearers showed a smaller percentage increase than the "low", and over the whole field the "high" trees showed a percentage increase of only 22.8 against 57.4 from the "low" trees. The actual pod yields per treatment and the percentage increases are set out in Table 7.

Table 7.

Treatments. N = nitrogen K = potash P = phosphate	"High" bearers. Yield in pods, 1931-33.	"High" bearers. Yield in pods, 1933-35.	"High" bearers. Increase in pods.	"High" bearers. Percentage increase.	"Low" bearers. Yield in pods, 1931-33.	"Low" bearers. Yield in pods, 1933-35.	"Low" bearers. Increase in pods.	"Low" bearers. Percentage increase.
No manures ..	1,434	1,679	245	17.1	228	252	24	10.5
P alone ..	1,362	1,540	178	13.0	204	233	29	14.2
N alone ..	1,659	1,593	—66	—3.9	391	520	129	33.0
N+P ..	1,165	1,166	1	0.0	265	354	89	33.6
K alone ..	1,365	2,029	664	48.6	270	450	180	66.7
K+P ..	1,763	2,590	827	46.9	371	740	369	99.5
N+K ..	1,796	1,931	135*	7.5*	239	411	172	72.0
N+K+P ..	1,458	2,206	748	51.3	256	541	285	111.3
All plots ..	12,002	14,734	2,732	22.8	2,224	3,501	1,277	57.4

* These figures are probably accidental. One of the four sub-plots, for no reason than can be detected on inspection of the trees, showed a large *decrease* after treatment. The other three showed a large increase, but the nett increase is of course reduced by the one aberrant sub-plot.

It is to be remembered that, by the method here adopted for a special purpose, the number of trees contributing to each square in Table 7 is only half the number considered necessary for a manurial experiment in the light of uniformity trials. For this reason the percentage increases shown must be interpreted with caution. A complete analysis of variance in the usual form, using the figures of 1931-33 to correct those of the experimental years, has been worked out for the "high" bearers and "low" bearers separately but need not be presented in full. It shows that the only increases statistically significant (*i.e.* liable to occur by chance less than once in a hundred trials) are those due to *potash* in both cases. *Phosphate in the presence of potash* in the case of the "low" bearers gives a further increase in yield.

Nevertheless there are other features that without rising to the high level of statistical significance are instructive, and comment may be made on the various treatments in turn.

Phosphate applied alone has had no discernible effect in either case, the difference between the percentage increases and those shown by the control trees being very small.

Nitrogen applied alone has evoked very different responses from the two classes of trees, and *nitrogen with phosphate* has almost identically the same effect, so that the two may be considered together. Whereas high bearers show no increase, and even, in the case of nitrogen alone, a decrease, the low bearers show in each case an increase of 33 per cent. There would seem to be here at least an indication that some poor bearers may benefit from applications of nitrogen.

Potash alone or in combination with nitrogen or phosphate is always significantly beneficial. The apparent exception in the case of high bearers receiving nitrogen and potash is due to abnormal behaviour of a single sub-plot, and though it cannot be explained is almost certainly accidental. Apart from this anomalous case, yield of heavy bearers does not seem to be affected one way or the other by addition of either nitrogen or phosphate, or both, to the potash applied, the percentage increases from K, K+P, and N+K+P being almost identical. The low bearers on the other hand, benefit by addition of either, and the increase due to the addition of phosphate and nitrogen together is even greater than would be expected from the increases shown when these two fertilisers are added to potash separately.

Conclusions.

(1) On a soil where chemical analysis shows potash to be relatively more deficient than phosphate both the high and the low bearers respond to applications of potash.

(2) Neither type of tree responds to phosphate in the absence of potash and while nitrogen tends during the first two years to decrease the yield of good bearers it has the reverse tendency with poor bearers which benefit from added nitrogen. This suggests that the heavy bearers possess a more powerful nitrogen absorbing apparatus, than the poor bearers.

(3) In the presence of potash, phosphate gives further increases of yield from the poor bearers. In the case of heavy bearers this is not apparent from the yield figures although the analysis suggests it is more important than appears.

Summary.

By analysing separately the yields from heavy and low bearing cacao trees in the same experiment it is revealed that on a potash deficient soil all trees respond to addition of potash but only the low bearers respond to additions of nitrogen and phosphates. This suggests absorption mechanisms which differ but whether the difference is due to genetic variation or to other causes is not obvious.

The general reaction to manures is greater for poor bearers than high bearers calculated as percentage increases in yield but the actual yield increase per tree is of course much smaller. In this respect the action of manures differs qualitatively from the action of favourable seasons.

STUDIES OF FRUITFULNESS IN CACAO

X.—Physiological Effects of Applications of Nitrogen, Potassium and Phosphorus on the Cacao Tree.

By F. J. Pound.

Preliminary observations of the behaviour of cacao trees in the field under natural conditions have been recorded in several papers in the Second and Fourth Annual Reports on Cacao Research. Their object was to discover how and when a cacao tree sets fruit, and why in many cases a large proportion is prematurely lost after setting. Particular attention was paid to the interrelationships of flushing, flowering, setting and wilting of cherelles. The conclusions reached may be briefly summarised as follows :—

1. *Flushing* occurs at approximately regular intervals, often associated with a change of weather but not always obviously so. There is presumably a normal life-cycle for each set of leaves, the length of which can only be shortened or lengthened by climatic conditions within certain limits.

2. *Flowering* varies widely both from tree to tree at any one time and on the same tree at different times in the crop cycle. There is little relation between flowering and fruit-setting, but a close one between self-compatibility of the flowers and fruit-setting. The important fluctuation is therefore in self-compatibility rather than in intensity of blossoming. One and the same tree may be self-compatible at some times and self-incompatible at others, and the factors governing this change, still to be discovered, are perhaps the most important in determining yield.

3. *Setting* occurs in a marked yearly cycle usually beginning in June and increasing steadily till disturbed by the July flush. Later in the season it is usually low in October and November and rises again in December. Setting is almost invariably checked by a flush, or change of leaf, presumably on account of competition between the flowers and the developing leaves for food materials. Some trees set steadily and continuously throughout the season and these are usually heavy bearers, whilst others are intermittent setters and poor bearers. Continuous setting can probably be traced back to continuous self-compatibility. Manipulations such as ringing of branches do not increase the proportion of flowers that set, nor affect the time at which setting occurs.

4. *Wilting* of young cherelles is considered to be largely due to physiological causes, though some of it may be traceable to primary fungal infection. Excessive rainfall, extreme dryness or a heavy flush of growth may all at times be major factors inducing wilting. Its incidence, however, is very variable on different trees. Some regularly produce abundant cherelles all of which fail; others produce few, of which most survive. Young fruits seem most susceptible to wilting between 40 and 60 days old, and this susceptibility is probably connected with the fact that they are then growing most rapidly and can least afford any check in nutrition, though there may possibly be in some cases other reasons connected with the embryogeny. Certain self-compatible trees given dressings of nitrate of soda, after fruit-setting and during a flush of growth, held many more fruits than did similar trees which were untreated; this, however, was an isolated observation.

From consideration of these findings it is fairly clear that if the time of flush or the time of setting, or both, could be in any measure controlled by suitable manuring, a powerful weapon would be available for the increase of yield. An acceleration of setting, or a delay of change of leaf, by preventing the coincidence of the latter with a large crop of cherelles in their most susceptible stage, might make a very great difference to the number of pods matured. For this reason the manurial experiment on Field 8, River Estate (already discussed from other points of view) has been kept under observation since it was laid down, to discover whether state of flush, flowering, setting, and wilting of cherelles would be affected in time as well as intensity by any of the treatments adopted. Preliminary remarks on the observations of the first year were given in the Fourth Annual Report on Cacao Research (1934), pp. 24-25, summarized as follows :

" Phosphate is generally significantly beneficial to setting. The effect of potash is somewhat obscured by the depressing effect of nitrogen applied in addition. Nitrogen alone improves setting, as was previously found for self-compatible trees, but here not significantly so."

" No definite conclusions can be drawn with respect to the effect of manures on wilting of immature fruits."

Covering the crop cycle 1934-35, after the trees had received a second dressing of fertilizers, observations were made fortnightly, half the trees being inspected in one week and the other half in the following week. For most of the period the observers were supervised by Mr. E. E. Pyke, to whom acknowledgement is due for the figures. In this second experimental year the results are much more definite, due no doubt in part to the greater frequency of observations and in part to the cumulative effects of the manuring.

The results are presented graphically in fig. 1, and the general course of events for the whole field can be read from the graphs. A flush was in progress when the observations commenced,

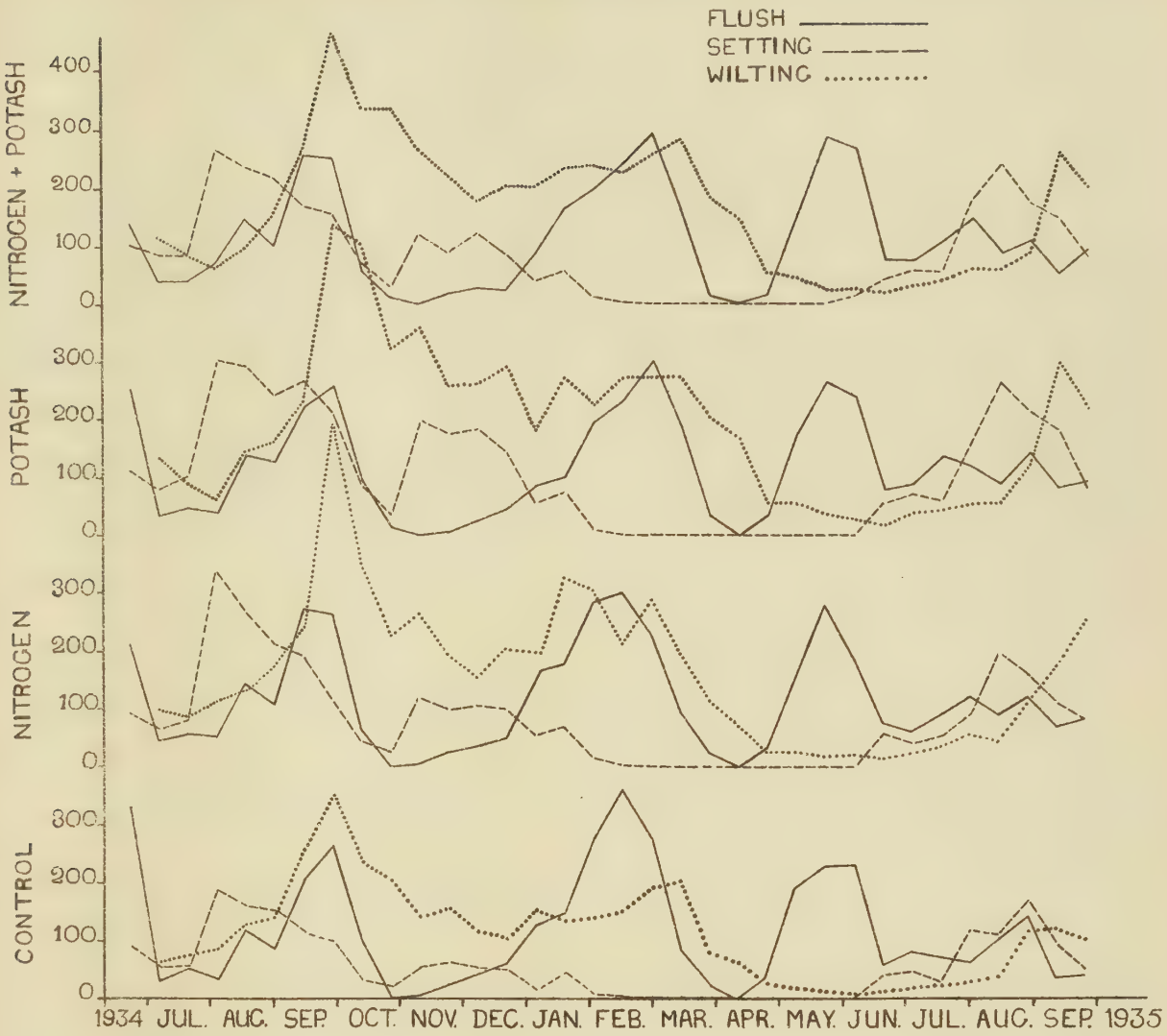

FIG. 1.—*Flush, setting and wilting of young fruits on trees under various manurial treatments. Fortnightly observations from 22nd June,* 1934 *to 26th September,* 1935.

and when it was over flowering and setting increased, reaching a peak in August. In September a second flush interrupted setting and induced heaving wilting. By November setting was increasing again and remained high through December, being practically terminated by the third flush of February, 1935. Another peak of wilting followed this flush, and for the next three months of the dry season there was little activity. The next cycle opened with a flush in May, 1935, which was not marked by a wilting peak because there were no cherelles to wilt, and after it was over flowering and setting began as in the previous year.

From inspection of the graphs it is at once quite evident that none of the manurial treatments has had any effect on the *time* of flushing, flowering, setting or wilting. On all plots the peaks of each activity occur together, and the only marked effects of the treatment are in *intensity* of setting and wilting.

Intensity of flowering and setting was increased in the latter part of 1934 on all the manured plots and on the phosphate sub-plots. The recorded setting from 19th July, 1934 to 3rd January, 1935 has been submitted to examination by analysis of variance, and the increases due to potash, nitrogen and phosphate all proved to be statistically significant. The increase on plots receiving both nitrogen and potash was significantly less than the sum of the increases on plots receiving either manure alone, and the interactions between the phosphate treatment on the sub-plots and the main plot treatments were very small.

The intensity of wilting was likewise higher on all treated plots than on the controls. The final effect of the manures, in terms of pods harvested, has been discussed in a previous paper in this Report, and it will be recalled that of the three salts applied only the sulphate of potash gave a significant increase in crop. This means that the increased wilting was sufficient in the case of

nitrogen and phosphate to counterbalance the increased setting, but in the case of potash it was not so much.

It is interesting to find setting improved by *all* treatments, but the more intricate problem, of retaining to maturity the young fruits that have been set, is not greatly advanced towards solution. Wilting does not appear on these facts to be due to any specific mineral deficiency, since it was increased by all treatments. In this experiment it appears rather to depend on the number of cherelles set. In other words, the more young fruits there are, competing for water and nutrients in general at a time of shortage, the more will be lost until the balance is adjusted. The effect of potash, showing that the balance can be adjusted at a higher level of fruitfulness when the chief mineral deficiency in the soil (known on this site to be potash) is corrected, lends support to this view, and suggests once more that the wilting problem is only to be attacked indirectly through the whole complex of factors that affect the health of the tree.

Summary.

1. Applications of sulphate of ammonia at a rate of 1,200 lb. per acre, sulphate of potash at a rate of 600 lb. per acre and superphosphate at a rate of 600 lb. per acre, alone or in combination, have had no effect in two years on the *periodicity* of flushing, flowering or fruit-setting of cacao trees.

2. Each of the applications caused a significant increase in the *intensity* of fruit-setting. In the cases of the sulphate of ammonia and the superphosphate applied alone, however, the increased setting was counterbalanced by increased wilting of cherelles. The sulphate of potash, containing the element known to be most seriously deficient on the site of the experiment, gave the greatest increase in setting, increased wilting to a relatively smaller extent, and on balance resulted in an increased yield.

B.—CHEMICAL AND ECOLOGICAL SECTION.

SUMMARY OF PREVIOUS RESULTS, AND THE CHEMICAL PROGRAMME OF 1935.

By F. Hardy.

The various problems studied during the past five years by the Officer for Cacao Research, Chemistry Section (Mr. J. A. McDonald), working in collaboration with the analytical staff of the College Chemistry Department (under the charge of Mr. G. Rodriguez), may be classified under the following main headings.

(I) The identification and description of good and bad environments, both atmospheric and soil, in relation to the growth of the cacao tree in Trinidad.

(II) Soil surveys, and the laboratory examination of a great number of soil samples collected from profiles representative of the main cacao soil-types occurring in Trinidad, Tobago and Grenada.

(III) Field manurial experiments designed to test the main indications furnished by the laboratory results.

(IV) The relationships between chemical composition of parts of the cacao tree (particularly the leaves) and the nutrient status of the soil.

(V) The effects of surface organic litter and vegetable mulch on the moisture and nutrient status of cacao soils.

(VI) The diagnosis of soil nutrient deficiencies by means of characteristic leaf symptoms and growth peculiarities.

(VII) The diagnosis of soil nutrient deficiencies by means of simple pot tests with suitable indicator plants.

(VIII) Phosphate relationships of gypseous soils that fail to support satisfactory cacao crops in Trinidad.

(IX) The rôle of manganese compounds in the fertility of cacao soils.

(X) The detailed investigation of local variations in soil fertility in collaboration with the College Department of Economics.

Considerable progress has been made in the study of each of these problems, and of others of lesser importance having bearing on the ecological relationships of the cacao tree. Some of the more striking and important conclusions so far reached are summarised below.

(1) "Good" cacao environments exhibit *high constancy in the moisture status of soil and atmosphere*; fluctuations are reduced to a minimum, and the tree is never subjected to sudden nor pronounced desiccation, as it is in "bad" cacao environments.

(*a*) These conditions are partly due to adequate protection from moving air, afforded by favourable topography, effective artificial wind-breaks and shelter belts, and ample shade-tree canopy. Efficient natural and artificial drainage, and suitable soil texture contribute to the result.

(*b*) The main physical environmental factor appears to be the evaporating ability of air (as measured by the Livingston Atmometer, which integrates relative humidity, air movement and insolation as a single value).

(*c*) Seasonal fluctuations in evaporating ability of air may readily be assessed in Trinidad by periodic measurements of relative humidity of the air at 2 p.m. by means of a pocket hygrometer. Fluctuations are highest in "bad" environments.

(2) Pronounced *vegetative activities*, (such as leaf flushing, flowering, fruit setting, shedding of flowers and fruits, blackening of fruits, and wilting of leaves), *are accompanied by distinctive changes in the moisture relations of the cacao tree and its environment.*

The incidence of *Thrips* attack in Trinidad seems to be connected with incipient drying of leaves following diminution in available soil moisture during periods of high atmospheric humidity.

(3) The *type of organic matter* forming a natural litter on the ground surface (but not necessarily the total amount of organic matter) appears to distinguish "good" cacao soils from "bad".

(*a*) High yields of cacao (over eight bags of 165 lb. weight per 1,000 pickets) are generally obtained on soils whose organic matter component in the surface 6-inch layer exhibits carbon-nitrogen ratios numerically greater than 9.5 (corrected value for total carbon).—Results for Trinidad, Tobago and Grenada.

(*b*) *Mycorrhiza* flourish in the highly organic cacao soils of Trinidad; they are associated with the finer roots and root hairs of the cacao tree; their hyphae penetrate into the cortical root-tissue. (See E. E. Pyke's paper, Fourth Annual Report on Cacao Research for 1934, pp. 41-48.) Both a high C/N ratio and a high level of available phosphate (to quote Pyke) "might be expected to exert a direct nutritional effect amounting perhaps to control upon the fungal flora of the soil, included among which is the assumed saphrophytic phase

of the mycorrhizal fungus, the organism possibly can no longer develop as a saprophyte when the plant-remains in the surface soil become highly humified". Further, "mycorrhiza may prove to be a biotic factor influencing the mineral nutrition of the cacao tree" . . . "any mechanism which may be able to short-circuit the process of transfer of mineral nutrients from the humic soil to the trees will be beneficial" . . .

(*c*) The indications that soil-organic matter only slightly decomposed (high C/N ratio) favours the incidence of mycorrhiza, which aid in the nitrogen and mineral nutrition of the cacao tree, may furnish a reason why soils containing high-ratio organic matter generally support cacao crops giving high yields.

(4) *Available phosphate is definitely deficient in the heavier types of cacao soils* of Trinidad, Tobago and Grenada, which regularly support trees of *low productivity*, other growth factors being favourable.

(*a*) Such soils respond readily and greatly to applications of *phosphatic manures*, usually within one year of application, and often to the extent of over 100 per cent. increase in crop yield (measured as weight of wet cacao).

(*b*) Certain loam and clayey soil-types are characterised by a natural low content of available phosphate. (Provisional limit of adequacy, 50 parts P_2O_5 per million parts of dry soil, surface 6-inches; Truog's method of estimation.) Examples of phosphate-deficient heavy cacao soils are:—

Brasso Clay Soil, Talparo Clay Soil, Charuma Clay Soil, most Alluvial Clay Soils, Princes Town Marl Black Soil, Green Clay Soil, Naparima Red Clay Soil, Moruga Silt Soil, Basse Terre Marly-Clay Soil; Grenada Red Earth Soil derived from basic igneous rocks, and Tobago Brown Earth Soils derived from basic igneous rock and metamorphic schists.

(*c*) Certain sandy soil-types also are phosphate deficient, (limit of adequacy, 30 p.p.m. P_2O_5), for example, the poorer kinds of Brasso Sand Soil and Moruga Sand Soil of Trinidad.

(*d*) A recent rapid extension of the cacao soil survey of Trinidad to the western, northern and eastern areas of the Island has further demonstrated a general marked deficiency of available phosphate, particularly in mixed Alluvial Clay Soils forming narrow river "vegas" and lagoon basins, that support only indifferent cacao crops. Extensive field experiments with phosphatic manures, based on this finding, are now being inaugurated (Dry Season, 1936) under the Cacao Relief Scheme by Officers of the Trinidad Department of Agriculture.

(*e*) It is often possible to demonstrate phosphate deficiency in soils by means of a simple pot culture test with some phosphate-sensitive indicator plant, such as Tomato, which develops a characteristic purple under-leaf colour when seedlings are grown in such soils.

(5) *Available potash is definitely deficient in many of the sandy types of cacao soils* of Trinidad and Tobago which support cacao trees of low productivity (Sandy soils are uncommon in Grenada, and are confined mainly to Alluvial Soils).

(*a*) Such soils respond to applications of *potassic manures*, almost as readily and greatly as the loam and clay soils respond to phosphatic manures.

(*b*) Certain sandy soil-types are characterised by a natural low content of available potash (Provisional limit of adequacy, 100 parts of exchangeable K_2O per million parts of dry soil, surface 6-inches). Examples of potash-deficient sandy cacao soils are:—the poorer kind of Brasso Sand Soil, Caroni Sand Soil, Nariva Sand Soil, Terrace Sand and Gravel Soil, the poorer kinds of Moruga Silt and Sand Soils, and of the Sandy Alluvial soils occurring in the Northern Range Valley "vegas" of Trinidad, and certain Sandy Alluvial Soils of Tobago.

(*c*) Field experiments with potassic manures are also being laid down as part of the Cacao Relief Scheme on sandy soil areas that appear to warrant further investigation (Dry Season, 1936).

(6) *Available nitrogen appears seldom to be deficient in the cacao soils* of Trinidad, Tobago and Grenada, except where erosion has removed the surface organic layer in areas that have become exposed to rain-washing.

(*a*) The circulation of nitrogen through leaf fall from cacao and leguminous shade trees maintains a high content of nitrogenous organic matter in the surface soil.

(*b*) Rapid nitrification occurs in the layer of organic matter in contact with the soil which includes most of the "feeding roots" of the cacao tree; such moisture and temperature conditions as are very favourable to the multiplication of micro-organisms prevail in this organic layer, and are maintained when its surface is replenished by further leaf-fall.

(*c*) The addition of vegetable mulch to cacao soils already provided with a surface layer of leaf litter does not depress available soil nitrogen; on the contrary, it may lead to a great increase in nitrate. This coincides with a proportionate increase in soil moisture, and is evidently caused by improvement in biological conditions favouring nitrification.

(7) The *reaction* of the cacao soils of Trinidad, Tobago and Grenada varies within wide limits, both vertically within individual profiles, and laterally for surface layers within areas of the same soil-type and of different contrasted soil-types. Whilst "good" cacao soils display a wide range of reaction (pH value), accumulating evidence indicates that the most suitable reaction for cacao is near neutrality (pH 7.0) or slight alkalinity.

(*a*) The significance of this conclusion is not yet clear. It has not been demonstrated that acidity, as such, is a harmful factor in cacao soils, nor has it been proved that abundant available calcium is necessary for the successful growth of the cacao tree. On the other hand, high pH values appear to accompany high contents of available phosphate, both for surface soil layers and for the different layers of individual profiles. The more alkaline cacao soils usually contain small amounts of calcium carbonate, but many calcareous parent rocks of West Indian cacao soils (notably the Princes Town Marl of Trinidad) are nearly devoid of phosphate, so that this component is not invariably bound up with free calcium carbonate. Furthermore, the presence of appreciable free lime in soil frequently causes the undesirable fixation of iron and manganese, which are regarded as essential accessory nutrients in plant growth.

(*b*) Certain preliminary liming experiments on acidic, phosphate-deficient, heavy cacao soils in Trinidad have demonstrated immediate benefit from the addition of ground limestone; liming is accordingly receiving attention in the experimental programme of the Trinidad Department of Agriculture under the Cacao Relief Scheme.

(8) The presence of *gypsum* (calcium sulphate) in certain cacao soils of Trinidad exercises a marked deleterious effect on the growth and productivity of the cacao tree. An explanation of this effect is being sought, but so far no conclusive results have been obtained.

(*a*) The gypseous types of soil have been derived from Miocene sedimentary rocks; they include Brasso Clay, Talparo Clay, Charuma Clay, Green Clay, and Naparima Red Clay.

(*b*) Deleterious effects due to gypsum are usually experienced where electrical conductivity values for soil-water mixtures demonstrate the presence of the mineral within about three feet of the ground surface.

(*c*) Gypseous soils are prone to severe landslip following waterlogging. Many hilly cacao areas of gypseous soil in Trinidad have suffered deep erosion from this cause, and the infertile gypseous subsoil thus exposed has failed to support replanted cacao trees, as well as other plants except grass. Roads constructed on the dip side of inclined gypseous strata are expensive to maintain because of repeated land slipping.

(*d*) Gypseous phosphate-deficient cacao soils give no response to phosphatic manure in field experiments. They are often deficient also in manganese, which may partly account for their failure to respond to manuring with phosphates.

(*e*) The manurial nutrient relationships of gypseous soils are being further studied in pot experiments.

(9) *Manganese compounds* appear to be a factor contributing to the fertility of cacao soils.

(*a*) Soils derived from igneous rocks and from calcareous sedimentary rocks in Trinidad, Grenada and Tobago contain greater amounts of manganese than soils derived from non-calcareous sedimentary rocks and from recent swamp and river alluvia.

(*b*) Many gypseous soils are characteristically deficient in manganese (*See* 8 (*d*)).

(*c*) In general, high-yielding cacao soils contain greater amounts of manganese than low-yielding soils belonging to the same soil-type.

(*d*) The effect of soil conditions (reaction, presence of lime, &c.) on the availability of manganese has not yet been specifically investigated, but a fair degree of positive correlation has been found between soil reaction (pH value) and total content of manganese, the more alkaline soils containing the greater amounts.

(10) The *diagnosis of nutrient deficiencies* by leaf symptoms and growth habit of the cacao tree has been found possible, especially in the case of *potash* deficiency, and with less certainty in cases of phosphate deficiency and nitrogen deficiency.

(*a*) The characteristic symptoms have been revealed by pot and tub sand-cultures, and by observations in the field within areas of soils of known nutrient status, and within the differently-treated plots of field manurial experiments.

(*b*) *Potash deficiency* is indicated by a crenulated (or scolloped) browning or scorching of the apical and lateral margins of the cacao leaves; this is a very characteristic symptom, and can easily be recognised in the field.

(*c*) *Phosphate deficiency* is suggested by long, "whippy", pendulous, thin side-branches which carry tufts of leaves at their extremities, but few or no leaves along the stem; this symptom is not always easy to recognise in the field; it is especially difficult to distinguish during periods of natural leaf fall.

(*d*) *Nitrogen deficiency* is indicated by stunted growth and small pale-green or yellowish leaves. Many other undesirable soil conditions, such as waterlogging, may produce this symptom; it is not definitely an indication of lack of nitrogen in the soil.

(*e*) It should be carefully noted that these symptoms are not necessarily directly and positively correlated with low values for these three nutrient entities as obtained by routine chemical soil analysis, but are associated rather with the *uptake* of nutrients from the soil. Nutrient uptake may not be directly related to "availability" of nutrients as revealed by laboratory analysis, as the results of manurial experiments demonstrate (*See* paragraph (12)).

(11) According to the researches of the College Department of Economics, under Prof. C. Y. Shephard, the *type of soil* seems to be the most important feature distinguishing *profitable* cacao lands from unprofitable.

(*a*) Local variations in productivity within any given area of a "good" type of cacao soil can generally be accounted for by damage to cacao trees by agencies such as falling shade-trees, insect pests, fungus diseases, careless cultivation, and unsatisfactory drainage, or in some cases by the occurrence of low-bearing genetic types of cacao.

(*b*) Thus, cacao fields on Chocolate Soil, River Alluvial Soil, and the better kind of Brasso Sand Soil of the Montserrat District of Trinidad, are much superior to those on gypseous Brasso Clay Soil in productivity, cost of production of cacao, and longevity of bearing trees.

(*c*) Unexplained local variations in productivity may be traceable to variations in soil fertility, and this possibility is being tested by detailed soil sampling and chemical analysis within areas specially selected by Prof. Shephard.

(12) *Chemical analysis of leaf material* representative of the foliage of cacao trees growing in different types of soil and on differently-manured plots in field experiments has demonstrated that the numerical ratios between the three nutrient entities, nitrogen, phosphate and potash, present in mature cacao leaves, clearly indicate deficiencies in one or more of these entities in the soil, and furnish a means of gauging the soil's manurial requirements.

(*a*) Chemical analysis of cacao *beans* proved unreliable for these purposes, because of great variation in composition between beans of different genetic strains of cacao which comprise the tree population within any given field or area.

(*b*) The nitrogen : potash ratio furnishes a useful index of "physiological condition" of cacao leaves. Its value is *greater* (i) for mature than for young leaves; (ii) for young leaves of trees growing in "bad" soil than for those of trees growing in "good" soil; (iii) for leaves of trees prone to attack by Thrips than for those of trees not attacked (possibly because chemical composition is related to leaf transpiration, which is higher in foliage liable to damage by Thrips).

(*c*) The chemical composition of cacao leaves can be appreciably altered by manurial treatments. On a phosphate-deficient *clay* soil, manuring with super-phosphate increased the potash content relative to nitrogen, and thus greatly decreased the nitrogen : potash ratio. On the other hand, manuring with potassium sulphate in the absence of phosphate manure produced no similar marked effect. On a potash-deficient *sandy* soil, phosphatic manure produced no definite effect on leaf composition, but potassic manure greatly decreased the nitrogen : potash ratio concurrently with an increase in yield of cacao. Hence, manures may act differently on the soil, depending on its *type*, and may therefore produce only indirect effects on yield and on leaf composition.

(*d*) By employing as standard of comparison the "ideal" nutrient ratios exhibited by cacao leaves of trees growing in a suitable environment and giving large yields of cacao, useful indications of nutrient deficiencies of soil, or of "lack of balance" in nutrient uptake, may be obtained by chemical analysis of leaf material. Chemical leaf analysis may thus provide an ecological method for diagnosing the chemical environment of cacao soils in the field.

(*e*) The cacao tree apparently requires adequate supplies of potash available to the absorbing roots in order to produce greatest growth and yield of cacao, but its direct phosphate requirements are not large. When potash uptake is adequate, additional benefit may be derived in some instances from nitrogenous manuring, but not otherwise. Deficiency of nitrogen, however, is not common in the soils of Trinidad, Tobago and Grenada.

(*f*) The cacao tree evidently is unable to absorb sufficient potash from soils whose contents of available phosphate are inadequate, possibly owing to inefficiency of the nutrient-absorbing root-system (perhaps involving Mycorrhiza co-operation) of trees growing under such conditions.

Scope of the Present (Fifth) Report.

Part I. (Soil Surveys) describes two more typical soils utilised for growing cacao in South-Central Trinidad, in the neighbourhood of Penal, Siparia, Basse Terre and Moruga. The more widespread soil-type is sandy or silty in texture (Moruga Sand and Silt Soils), and has been derived from siliceous and frequently slightly calcareous, soft sandstones or silty claystones, generally finely bedded, though occasionally massive. The colour of the soil is sepia-brown in the humic surface layers, and fawn-grey or yellow ochre below. The reaction is markedly acidic (pH 5.8); available phosphate is deficient, but available potash is adequate or nearly so. The sandier kinds of Moruga Soil probably exhibit unsatisfactory water relationships, the silty kinds in this respect are more favourable to the growth of cacao.

The second soil-type has been derived from calcareous claystone; it is developed around Basse Terre. It is a tough, hard clay soil, acidic in the upper layers down to about 1½ or 2 feet depth, below which the reaction is alkaline, owing to the occurrence of increasing amounts of calcium carbonate. Available phosphate is deficient, but available potash is plentiful. Gypsum is usually absent, and the soil might therefore respond to phosphate manuring.

Part II deals with manurial experiments, and presents results covering periods in certain instances of three consecutive years' duration. Phosphatic manure appears not to give successive continual increases in yield on phosphate-deficient, non-gypseous, acidic, heavy cacao soils; the results show that, after a few yearly applications, little further increase is obtained by phosphate manuring alone; the soil might now further respond to potash, and perhaps to nitrogen in addition.

Superphosphate gives a slightly greater increase in yield in the first year than finely-ground rock phosphate when applied to such soils.

The results of an experiment designed to compare the effects of manuring on shaded and unshaded cacao growing in potash-deficient soil have indicated that the presence of Immortel shade-trees may *not* adversely affect the response of the cacao tree to artificial manures, as has generally been assumed; the shaded trees responded even more than the unshaded, particularly to applications of potassic manures.

Part III presents laboratory data which indicate that deficiency in manganese compounds in cacao soils may be one of the factors contributing to their infertility, and may partly explain why gypseous soils do not respond to phosphate manuring.

Part IV deals with cacao fermentation. It describes a new form of fermentation box, devised by Mr. McDonald, in which the sun's heat is utilised for raising or maintaining the temperature of a fermenting mass of wet cacao beans. The method is particularly applicable to small amounts of cacao. It should prove of considerable value in laboratory biochemical investigations of the complex changes which cacao undergoes during fermentation; it may serve the needs of peasant proprietors of small cacao holdings, and of native producers of cacao.

Plans for Future Investigations.

Hitherto, the work of the officer of the Chemistry Section of Cacao Research has mainly concerned soil studies and the initiation and recording of field manurial experiments. Since the inception of the Cacao Relief Scheme in Trinidad in January, 1936, most of the manurial experiments now in being have been taken over by the Agricultural Department of Trinidad and Tobago, so that the services of the Research Officer are now available for work of a different nature.

(1) *Biochemical Investigations.*

Recognising the need for further information regarding the factors that distinguish good cacao from bad, and that differentiate the well-known varieties of commercial cacao (such as Calabacillo, Forastero and Criollo), it is considered desirable to investigate the biochemical composition of both raw and fermented cacao belonging to these several categories, with the ultimate object of defining the chemical attributes of "quality" in cacao. For example, the changes that the tannin component of the cacao bean undergoes during fermentation seem to be particularly important, and the possible differences which the several varieties of cacao exhibit in respects to the tannin component may partly decide their commercial value. The effects of manurial treatment on the biochemical composition of the cacao bean may also be worth investigating. To these ends, the applicability of the new solar fermentory (described in Part IV of the present report) to the preparation of small batches of beans in different stages of fermentation seems obviously to be suitable. Furthermore, the existence in Trinidad of a range of large-scale manurial experiments, laid down on various types of soil, bearing different kinds of cacao trees, and treated with different organic and artificial manures, should provide material for a study of the effects of environmental conditions on the biochemical composition of the cacao bean.

(2) *Nutrient Relations of Cacao Soils.*

It is not proposed to discontinue all other lines of work previously initiated; there remain many promising subjects that deserve further consideration. Thus, sufficient is not yet known of the nitrogen, phosphate and potash relationships of cacao soils, both in the West Indies region and elsewhere. It is therefore intended to continue the examination of West Indies cacao soils, and to extend the detailed survey of cacao areas, particularly with a view to deciding which soil-types may profitably be improved by suitable

treatment, and which types should be planted in other crops, or altogether abandoned. The manurial and cultural treatment of gypseous soils deserves further study, and the effect of liming acidic cacao soils requires investigation, as well as the possible rôle of the rarer accessory nutrient elements, including iron and manganese, in the productivity of cacao soils.

(3) *The Cacao Soils of West Africa.*

In order to test the applicability of the scheme of physical and chemical analysis devised at the College, to cacao soil problems in West Africa, the co-operation of agricultural chemists on the staffs of the Departments of Agriculture in the Gold Coast Colony and in Nigeria has been sought. Arrangements have been suggested whereby representative profile soil samples may be collected in West Africa, and shipped to the College for laboratory examination. The results obtained should further elucidate the nutrient relationships of the cacao tree growing in a wider range of soils and under climatic conditions differing somewhat from those occurring in the West Indies region so far considered.

PART I.

CACAO SOIL SURVEYS.

(3)—Siparia-Penal-Moruga District of Trinidad.

By F. Hardy and G. Rodriguez.

(I) Introductory.

Soil investigations conducted in field and laboratory with the object of describing the cacao soils of Trinidad so far have been confined to the Montserrat (Central Range) District (1), and to the Rio Claro District (2). During 1935, two further cacao soil-types occurring in south-central Trinidad (Penal-Siparia-Moruga District) were studied. These additional types have been provisionally named (A) Moruga Sand and Silt Soils, and (B) Basse Terre Marly-Clay Soil. The first is the more widespread and important; it comprises estate and peasant cacao lands that lie around Penal and to the south of that village, as well as a few larger estates and peasant lands near Moruga. The second comprises estates lying around Basse Terre, north of Moruga. Examples of both these soil-types were studied by the profile method, which has been fully described in a previous publication (1), and need not therefore be explained here.

(II) Description of the Parent Rocks.

(*A*) *Moruga Sands and Silts* (Upper Miocene).

Waring (3, p. 64) describes the Moruga Sands and Silts as cross-bedded, coarse-grained deposits, alternating with thin calcareous sandstones and shaly silts, containing much finely-divided carbonaceous matter. They are very irregular in composition; their contents of sand (particles whose sizes range from 0.04 to 2.0 mm.) vary between 10 and 92 per cent. Their colour is ochre-brown, yellow, dark grey, or pale bluish, greenish or purplish-grey, depending partly on the content of free iron oxide. The more sandy representatives are usually loose and incoherent, though occasionally cemented into hard masses by iron oxides or calcium carbonate.

Chemical analysis of parent rock material obtained at depths between five and six feet (*See* Table I) show only traces of free calcium carbonate, but doubtless deeper-seated, less altered rock may occasionally contain appreciable amounts, especially where hard calcareous bands occur in soft sandstones. Thus, Wall and Sawkins (4, p. 133) report contents of calcium carbonate as large as 14, 22 and 37 per cent. in specimens of Moruga calcareous sandstones suitable for building purposes.

The chief mineral component of the Moruga Sands and Silts is quartz, which may amount to more than 50 per cent. of the rock. White mica is often abundant and conspicuous, and felspars are usually present, though ferromagnesian minerals are generally scarce. The original source of the material is believed to have been the basement metamorphic and igneous rocks of the highlands of Guiana.

The total content of potash in the parent material of the Moruga Sands and Silts is not particularly high (Table I) (namely, 1.5 per cent.) but total phosphate is very plentiful, whilst manganese oxide is only appreciable. Gypsum is usually not present.

(*B*) *Basse Terre Marly-Clay* (Lower Miocene).

The parent material of the marly-clay cacao soils occurring in the neighbourhood of Basse Terre, north of Moruga, is usually Lower St. Croix Claystone (Waring), a calcareous shallow-water formation marking the beginning of the Miocene deposition in South Trinidad. Other Lower Miocene and Oligocene calcareous formations occurring in Trinidad have been differentiated by geologists, namely, Princes Town Marl (a highly calcareous material), Green Clay (less calcareous and often highly gypseous), and Ally's Creek Beds. Since their identity and geological relationships have not yet been finally settled, it is proposed to term the calcareous Lower Miocene deposits of South Trinidad "*Ally's Creek Beds*" because this term has priority in the published literature. Occasionally, the more calcareous

finer-grained representatives of the Lower Moruga Sands (*e.g.* Profile No. 14) give rise to somewhat similar soils to those derived from the Ally's Creek Beds, but their texture is silty rather than clayey.

The parent marly clay of the Basse Terre soil is a dark sepia-grey, blue-green or almost black, compact claystone, generally showing well-marked bedding and very distinctive sub-angular or conchoidal fracture. Occasionally it is iron-stained and may contain concretionary iron oxide nodules. It is greasy or graphitic to the touch, and generally very uniform in appearance. It easily breaks up into flat angular fragments. Chemical analyses of material obtained at depths between five and six feet (Table I) show calcium carbonate contents ranging between 0.5 and 10 per cent. The total content of potash (Table I) is nearly the same as that of the Moruga fine sands or silts, namely 1.2 per cent. Total phosphate is quite high in amount (0.33 per cent.), and manganese oxide is present in appreciable quantity. The parent material resembles Brasso Clay in chemical composition, except that its phosphate content is much higher; it also resembles it in that it sometimes contains gypsum. The Moruga Sands and Silts give rise to soils in which the presence of the harmful gypsum component, so detrimental to the growth of cacao, need not generally be suspected, but the Ally's Creek Marly-Clay may occasionally produce soil containing appreciable amounts of this undesirable substance.

(III) Description of the Soil-types.

Laboratory data obtained for the surface 6-inch layer of representative samples of each of the soil-types are set out in Table II. The full profile data are not presented in this article; they are reserved for publication in a detailed account of the cacao and forest soils of South-Central Trinidad in course of preparation (5). The surface 6-inch layer appears to contain most of the feeding roots of the cacao tree, so that chemical examination of surface soil usually furnishes sufficient evidence of mineral nutrient deficiencies. For purposes of comparison, data for the main soil-types occurring in the cacao lands of the Montserrat and the Rio Claro Districts of Trinidad are included at the bottom of the table.

(A) Moruga Sand and Silt Soils.

(1) The *sandy soil-type* is represented by profiles Nos. (4), (9), (21), (26), (6) and (20), whose Index of Texture values range from 5 to 20. The general *colour* of the soil seen in 6-foot profile is fawn-grey, stained dark grey-brown by organic matter in the upper layers down to about the 3-foot depth (which is deep penetration, even for sandy soil). The soil below two feet is more-or-less stained red-brown in patches and splotches by iron oxides. The *texture* throughout is loose, friable and powdery, though often very compact below. The *reaction* is only slightly acidic (pH6.2 to 6.6) in the surface 3-inch layer, becoming progressively more acidic down to the 2-foot depth (pH 5.0) below which it becomes less acidic again almost to neutrality. Free calcium carbonate occurs in none of the sand profiles studied; profound leaching has apparently removed all traces of lime, even down to the 10-foot depth. *Organic matter* is abundant only in the surface 3-inch layer (two to five per cent., average four per cent.); the second 3-inch layer contains only half this amount. The soil between the 6-inch and the 36-inch depths contains between 1.0 and 0.3 per cent. of organic matter, but traces are found down to the 5 or 6-foot depths. The carbon-nitrogen ratio is high in the surface humic soil (about 10.5) but falls rapidly below (to about 5.5). The type of organic matter is therefore characteristic of that of a good cacao soil. Nutrients are confined mainly to the surface 6-inch layer. Available *phosphate* is very deficient (first 3 ins., 8 to 30 p.p.m., average 19 p.p.m.; second 3 ins., average 10 p.p.m.),

Table I.

Chemical Composition of Parent Rock Materials.

Parent Rock.	Free Calc. Carb. ($CaCO_3$) %	Total Silica (SiO_2) %	Alumina (Al_2O_3) %	Iron Oxide (Fe_2O_3) %	Potash (K_2O) %	Lime (CaO) %	Mag-nesia (MgO) %	Man-ganese oxide (MnO) %	Total Phos-phate (P_2O_5) %	Comb. Water (H_2O) %
(A) Moruga Sandstone	0.0	78.7	10.7	3.6	1.5	0.3	1.2	0.04	0.81	3.0
(B) Marly Clay	3.4	57.7	19.9	7.3	1.2	2.7	1.7	0.06	0.28	6.3
For Comparison (Montserrat District).										
Glauconitic Sandstone	(42.0)	30.4	10.9	21.5	1.65	19.3	2.5	0.26	0.16	—
Brasso Clay	(2.0)	54.1	19.7	11.2	2.96	2.0	1.9	0.05	0.06	—
Brasso Sand	(0.0)	74.4	12.2	5.3	2.57	0.7	0.9	0.06	0.03	—

and available *potash* is generally not quite adequate (180 p.p.m. surface 3 ins. ; 90 p.p.m. second 3 ins.). Below the top 6-inches, both available phosphate and available potash diminish rapidly, and the altering rock is so deep-seated that the roots of plants would need to penetrate to depths exceeding 6 feet before reaching a store of potential nutrients. In some instances (for example, profile Nos. 6 and 21) evidences of a wet season water-table at 2-foot depth are discernable, implying water logging during rainy weather. In no case is the presence of gypsum indicated by the soil analyses.

(2) The *silty soil-type* is represented by profiles Nos. (10), (24), (27), (7), (19), (23) and (3), whose Index of Texture values range from 21 to 30. The general *colour* is similar to that of the sandy type, except that orange and red iron-oxide staining is more conspicuous in the subsoil. The soil is fairly *coherent* and often somewhat plastic when wet, and hard and compact at the lower depths. The *reaction* is acidic (pH 5.9) in the surface 3-inch layer, becoming more acidic (pH 5.0) to the 3-foot depth, below which it becomes decreasingly acidic again. The subsoil below the 5-foot depth is generally alkaline (pH 7.8), and may contain traces of free calcium carbonate. *Organic matter* is plentiful in the surface 3-inch layer (three to seven per cent., average five per cent.), but diminishes rapidly below, being less than one per cent. in the second 6-inch layer. Organic penetration is nevertheless fairly deep (two feet), but not so deep as in the sandy type. The carbon-nitrogen ratio of the organic matter is about the same as that of the sandy type. Nutrients are mainly confined to the surface 6-inch layer. Available *phosphate* is generally deficient (first 3 ins., 10 to 40 p.p.m., average 29 p.p.m. ; second 3 ins., five to 20 p.p.m., average 14 p.p.m.). Available *potash* is probably nearly adequate (200 p.p.m., surface 3 ins., 100 p.p.m., second 3 ins.). Below the top six inches, both available phosphate and potash diminish rapidly down to the 4-foot level, but available phosphate increases very greatly below this, rising suddenly to over 300 p.p.m. where traces of free lime occur, and where the reaction is alkaline. Rates of solution are also high below the 4-foot depth, indicating that plant roots need not penetrate so deeply in the silt type of soil as in the sand type in order to reach a zone rich in potential nutrients. Gypsum is apparently absent throughout the profile.

The silty type of Moruga cacao soil is considerably better than the sandy type. It is not so deeply weathered nor leached ; it is richer in organic matter, and its contents of available phosphate and potash are somewhat higher. Both sorts of soil are decidedly *deficient in available phosphate, and available potash is only on the border line of adequacy.* The Moruga Sand and Silt Soils should benefit from phosphate and potash manures. The sandier soils that contain only small amounts of organic matter (less than two per cent.) might also benefit from nitrogenous manure.

The tendency of the Moruga Sandy Soil to lose moisture excessively during dry weather, together with its inferior nutrient status and great depth of profile, suggest that certain areas of such soil could not be expected to produce remunerative cacao crops when prices are low ; some alternative crop (for example coconut, coffee, or grapefruit) might prove more profitable. On the other hand, the Moruga Silt Soil may be worth retaining under cacao, and it might prove profitable to apply phosphate manure where higher yields are desired.

(B) Basse Terre Marly-Clay Soil.

This type of soil, derived from calcareous clay-stone, is represented by profiles Nos. (12) and (15), occurring within the Basse Terre area, whilst No. (14) represents a marly-silt soil derived from a calcareous facies of the Moruga Silt. The first two soils show Index of Texture values around 37, whilst the other has a lower value, namely 21. Except for the occurrence of a layer rich in calcium carbonate at the 5-foot depth, the Moruga Marly-Silt Soil closely resembles the Moruga Silt Soil described in the last section ; it need not here be further considered.

The *Basse Terre Marly-Clay Soil* shows the following main features. The general *colour* of the soil in profile is very dark leaden-grey, or brownish-grey, quite different from the paler fawn-grey colour of the Moruga Sand and Silt Soils. The parent partly altered, bedded and highly fissile, calcareous and occasionally gypseous claystone appears about the 4-foot depth. The soil below the surface humic layer is a tough, hard, scarcely friable, waxy, clay. The *reaction* is nowhere more acidic than pH 5.5. The surface soil (top 6 ins.) shows a slightly acidic reaction (p.H 6.3), becoming more acidic below, but the subsoil at the 1½ to 2-feet depth is generally quite alkaline (pH 7.2 to 8.1), because of the presence of free calcium carbonate. *Organic matter* is very abundant in the surface. 3-ins. layer (about eight per cent.). Its carbon-nitrogen ratio is fairly high (about 9.5). Its amount diminishes rapidly downwards, being less than one per cent. at the 12-inch depth. The deeper subsoil still contains about 0.7 per cent. of apparent organic matter (carbon-nitrogen ratio, 4.5), although it may consist of carbonaceous or hydrocarbon residues not derived from recent vegetation.

Available *phosphate* is deficient in the surface soil (first 3-ins., 32 p.p.m.; second 3-ins., 13 p.p.m). Its amount increases rapidly, however, at depths below three feet, and may reach values above 100 p.p.m. at the 4-foot depth where calcium carbonate is relatively abundant. Available *potash* is quite high in amount (214 p.p.m., surface 6 ins.), and much more plentiful than in the Moruga Sand and Silt Soils.

The Basse Terre Marly-Clay Soil would generally be expected to *benefit from phosphate manures,* except where gypsum is present, but potash manures may not be needed for the purpose of increasing its productivity for cacao.

Table II.—Cacao Soils.

Prof. No.	Site.	Surface 6-inch Layer. I.T.	pH.	O.M.	Rate of Soln.	Avail. P_2O_5	Avail. K_2O	Second 6-inch Layer. I.T.	pH.	O.M.	Rate of Soln.	Avail. P_2O_5	Depth of carbonate layer (ins.)
	(A) NON-CALCAREOUS SOILS.												
	(I) Moruga Sand and Silt Soils.												
	(a) Penal.												
3	Main Rd. 6¾m.	26	5.8	5.0	99	19	144	23	5.5	1.1	8	6	72
23	Rock Rd. ½m.....	24	5.9	3.0	54	10	96	27	6.2	1.1	7	7	nil
27	Main Rd. 7½ m.	13	4.9	2.9	15	36	121	21	4.3	1.0	7	5	60
24	Rock Rd. 3½ m.	13	5.5	2.6	18	12	177	23	4.8	1.0	3	1	72
26	Rock Rd. 2½ m.	9	5.9	2.4	20	13	197	7	4.8	0.7	3	1	nil
4	Main Rd. 7 m.	5	4.6	2.1	11	26	78	3	4.3	1.1	4	14	nil
	(b) Moruga.												
19	St. George Est.	26	6.8	3.9	(201)	22	244	24	6.1	0.9	(35)	4	60
20	Henry Estate....	22	6.4	3.9	(169)	17	148	18	6.0	1.7	11	12	40
21	Henry Estate	14	6.2	3.3	62	14	78	7	5.0	0.8	8	6	nil
	(c) Other Sites.												
7	Mor. Rd. 7¾m.	22	6.0	3.2	83	19	154	24	5.8	1.1	18	7	66
6	Douglas Tr.	17	5 7	2 8	47	7	70	13	5.0	0.6	3	2	nil
10	Scott Trace	21	6.5	4.2	79	30	130	18	5.8	0.9	9	19	48
9	Coora	7	5.7	1.8	31	19	156	10	4.7	1.1	4	8	nil
	Means	**17**	**5.8**	**3.2**	**47**	**19**	**138**	**17**	**5.3**	**1.0**	**7**	**7**	—
	(B) CALCAREOUS SOILS.												
	(III) Basse Terre Marly-Clay and Marly-Silt Soils.												
	(d) Basse Terre.												
12	Lorencite Est	50	6.2	5.8	170	17	188	39	5.9	0.8	9	12	24
15	San Jose Est.....	45	5.8	4.5	143	27	240	42	6.0	0.9	35	7	14
14	S. Antonio Est.	16	5.7	3.4	81	12	73	15	5.4	1.4	9	5	60
	Means	**37**	**5.9**	**4.6**	**131**	**19**	**167**	**32**	**5.8**	**1.0**	**18**	**8**	—
	For Comparison ; Montserrat District ; Rio Claro District.												
	Montserrat District												
	Chocolate Soil	43	7.2	6.0	175	343	309	39	7.0	2.2	50	23	—
	Brasso Sand (Good)	22	6.6	3.3	131	53	435	18	6.2	0.9	11	212	—
	Brasso Clay (Good)	37	6.9	4.4	166	71	145	34	6.5	1.5	47	150	—
	Brasso Sand (Bad)	14	5.7	1.7	43	24	79	15	5.2	0.5	10	(87)	—
	Brasso Clay (Bad)	40	6.6	3.9	121	(71)	151	37	6.4	1.3	30	(123)	—
	Charuma Clay (Bad)	44	5.5	5.1	84	29	112	41	5.3	1.4	19	9	—
	Rio Claro District												
	Princes Town Marl....	62	6.6	6.1	164	17	227	54	6.8	1.3	81	15	—
	Green Clay (Bad)	47	5.5	3.9	71	15	169	45	5.2	1.1	15	4	—
	Means : Good	**41**	**6.8**	**4.9**	**159**	**121**	**279**	**36**	**6.6**	**1.5**	**47**	**100**	—
	Bad	**36**	**5.8**	**3.6**	**80**	**23**	**128**	**34**	**5.5**	**1.1**	**18**	**6**	—

Limits for Adequacy :

(A) Sandy Soils.—Avail. Phosphate ; 30 p.p.m. P_2O_5
Avail. Potash ; 100 p.p.m. K_2O

(B) Clay Soils.—Avail. Phosphate ; 50 p.p.m. P_2O_5
Avail. Potash ; 150 p.p.m. K_2O

Except for its close texture (which may prevent suitable water movement and root penetration), and the occasional presence of gypsum, and its low phosphate status, the Basse Terre Marly-Clay Soil appears to be a fairly good cacao soil. Its cohesiveness and impenetrability are somewhat lessened in the surface 6-ins. soil layer by the presence of abundant exchangeable calcium (degree of saturation above 90 per cent.), and by a high content of organic matter. Apart from occasional unsuitable texture, the Basse Terre Marly-Clay Soil somewhat resembles the Princes Town Marl Black Soil occurring in certain cacao estates of the Rio Claro District.

(IV) Summary and General Conclusions.

(1) Moruga Sand, Moruga Silt and Basse Terre Marly-Clay Soils comprise most of the productive cacao soils of the South-Central region of Trinidad (Penal-Siparia-Moruga District). (The gypseous *clay*-types of soil that also occur in this region are mainly under forest growths).

(2) The *Moruga Sand and Silt Soils* differ mainly in texture. Both are deficient in available phosphate, but the silty type is less deficient in available potash. Both could be expected to benefit from phosphate manure, and the sandy type from potash manure, and, in some instances, from nitrogenous manure in addition. Certain areas of Moruga Sand Soil might be more profitably planted in crops other than cacao whilst cacao prices remain low.

(3) the Basse Terre *Marly-Clay Soil* is somewhat close textured, otherwise its chief deficiency is available phosphate.

(4) None of the soils usually contains gypsum in harmful quantity.

(5) Manurial experiments, involving phosphate and perhaps potash, should be laid down on all three types of soil.

(V) References.

(1) Studies in West Indian Soils; (VII) The Cacao Soils of Trinidad (A) Montserrat District. J. A. McDonald, F. Hardy and G. Rodriguez. *Imp. Coll. Trop. Agric.*, Oct. 1933, pp. 1-50.

(2) Cacao Soils Surveys (Princes Town Marl and Green Clay Soils of the Rio Claro District). Fourth Annual Rept. on Cacao Research, 1934. *Imp. Coll. Trop. Agric.*, 1935, pp. 51-53.

(3) *The Geology of the Island of Trinidad, B.W.I.* G. A. Waring. The Johns Hopkins Press, Baltimore, U.S.A., 1926.

(4) *Report on the Geology of Trinidad.* G. P. Wall and J. G. Sawkins. London, Longmans, 1860.

(5) Studies in West Indian Soils; (X) The Cacao and Forest Soils of Trinidad (B) South Central District. F. Hardy, D. W. Duthie and G. Rodriguez. *Imp. Coll. Trop. Agric.* (In preparation.)

PART II.

MANURIAL EXPERIMENTS ON CACAO.

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Introduction.

The results of preliminary manurial experiments on cacao were presented fully in the Fourth Annual Report on Cacao Research. These results were based on records of two consecutive crops (1933 and 1934) reaped subsequent to the application of manures. With a crop such as cacao, it is often difficult to demonstrate statistical significance of differences in yield due to treatment when the records from one crop alone are considered. This is due to the very large natural variation in the yield of individual plots in an experiment during any one year. When two consecutive crops are considered together, part of this natural variation in yield is smoothed out, and differences in yield due to treatment become clearer. Records are now available for the 1935 crop from some of these preliminary experiments, and certain further differences in yield due to treatment are indicated. As was expected, the yield of individual plots for this one crop are erratic, and a full statistical treatment of the experimental results will therefore be postponed until the 1935 and 1936 crops can be considered together and compared with the combined 1933 and 1934 records.

In addition to the 1935 records from the first series of experiments, one crop's records are now available from two of the new experiments which were laid down at a later date. These records are presented and discussed in this report, but a full statistical treatment of the results is being postponed until two consecutive crops can be considered together.

(A) PHOSPHATE EXPERIMENTS.

SERIES I.—SUPERPHOSPHATE EXPERIMENTS.

(1) Las Hermanas.

Soil Type.—Alluvial Clay, acidic in reaction.

Age of Trees.—Thirty to thirty-five years.

System of Replication.—One 4 × 4 Latin Square.

Size of Individual Plots.—18 trees.

Treatments:—1—Control.
2—1 lb. superphosphate per tree.
3—2 lb. do.
4—3 lb. do.
5—½ Plot: 2 lb. potassium sulphate per tree.

Table I.

Las Hermanas Estate: Superphosphate Experiment.

PLOT YIELDS (1933 AND 1934), AND ½ PLOT YIELDS 1935: WEIGHT OF WET CACAO (LB).

1933

A 80	D 72	B 55	C 37
C 70	A 114	D 68	B 39
B 50	C 81	A 69	D 47
D 60	B 31	C 68	A 49

1934

A 56	D 33	B 22	C 14
C 24	A 45	D 46	B 16
B 31	C 42	A 48	D 29
D 23	B 13	C 42	A 49

1935

28 A 34	39 D 45	13 B 21	35 C 22
20 C 26	34 A 29	30 D 18	16 B 31
13 B 15	32 C 20	52 A 43	28 D 44
29 D 38	45 B 21	21 C 44	35 A 28

The main plot treatments have been applied annually since 1932, and the half-plot potash treatment was first applied in 1934. Thus, previous to the 1935 crop, there have been three annual applications of superphosphate and one application of potassium sulphate.

Results.—The yield records for 1933, 1934 and 1935 are presented in Table I. The summarised results are presented in Tables II and III. The 1933 and 1934 results have already demonstrated the great value of manuring cacao with superphosphate in this area. The experiment is being continued for a further period of two years in order to discover whether further benefit may be derived from continued yearly application of superphosphate. The 1935 records indicate the following effects of the three annual applications.

Table II.

Las Hermanas Estate: Superphosphate Experiment.

COMBINED YIELDS FOR 1933, 1934 AND 1935. WEIGHT OF WET CACAO (LB.).

Treatments Superphosphate per tree.	YIELDS IN LB. WET CACAO.			
	1933	1934	1935	Total.
3 lb.	312	198	283	**793**
2 lb.	247	131	220	**598**
1 lb.	256	122	271	**649**
Control	175	82	175	**432**
Total for each season	**990**	**533**	**949**	—

Table III.

Las Hermanas Estate: 1935 Yields.

WEIGHT OF WET CACAO FROM POTASH TREATED HALF-PLOTS.

Half-Plot Treatments	YIELDS IN LB. WET CACAO. Main Plot Treatments Superphosphate lb, per tree.				Half-Plot Total Yields.
	3 lb.	2 lb.	1 lb.	Control.	
Potash	155	124	130	104	**513**
No Potash	128	96	129	71	**424**
Main Plot Total Yields	**283**	**220**	**259**	**175**	—

(1) The striking increases in yield obtained during 1933 and 1934 from the phosphate-treated plots have been maintained in 1935, but there has been no *additional* increase in yield from the 1935 crop.

(2) The continued application of the heavier dressings of superphosphate (2 lb. per tree and 3 lb. per tree) appears to be definitely in excess of the requirements of the cacao trees on this soil type. There is a strong indication that plots receiving these heavy dressings have shown a slight decrease in yield during 1935 as compared with the control plots.

(3) When the superphosphate is applied as a light dressing (1 lb. per tree), additional increases in yield are still obtained after the third consecutive annual application of manure.

(4) A definite increase in yield due to potash manuring is indicated for the 1935 crop (Table III).

(5) The great differences in yield between two successive crops are clearly shown by the summarised results in Table II. The records emphasize the necessity for considering two consecutive crops together when assessing the results of manurial experiments on cacao.

(2) Rio Claro I and Rio Claro II.

Soil Type.—Black Calcareous Clay (I); Gypseous Clay (II).

Age of Trees.—Twenty to twenty-five years.

System of Replication.—One 3×3 Latin Square (I). Two 3×3 Latin Squares (II).

Size of Individual Plots.—16 trees.

Treatments:—1—Control.
2—1½ lb. superphosphate per tree.
3—3 lb. superphosphate per tree.

First application of manures was made in May 1932; second application in May 1934.

Results.—The yield records for 1933, 1934 and 1935 are shown in Table IV. No further records are being taken from this experiment, therefore a final detailed statistical examination has been made of the records from Rio Claro I. The summarised results are presented in Tables V and VI. No statistical examination has been made of the records for Rio Claro II. The summarised results in Table VII show that there is no difference in the mean yield from different treatments over a period of three years, while the small differences between different treatments for any one year are obviously not statistically significant. The results in Tables V, VI and VII show the following effects of superphosphate on yield of cacao in this area (black marl soil).

Table IV.

Rio Claro Phosphate Experiment. No. of Pods per Tree.

Rio Claro I.

1933.			1934.			1935.		
B	C	A	B	C	A	B	C	A
41	25	15	28	27	3	47	39	14
A	B	C	A	B	C	A	B	C
20	32	25	14	22	21	23	35	35
C	A	B	C	A	B	C	A	B
22	12	21	17	4	9	29	8	17

Rio Claro II.

1933.			1934.			1935.		
B	C	A	B	C	A	B	C	A
19	22	20	14	15	14	31	27	16
A	B	C	A	B	C	A	B	C
30	19	18	13	13	8	23	20	18
C	A	B	C	A	B	C	A	B
19	10	13	6	2	4	21	8	14
B	C	A	B	C	A	B	C	A
12	7	15	9	6	6	22	17	15
A	B	C	A	B	C	A	B	C
15	15	12	7	13	3	18	19	15
C	A	B	C	A	B	C	A	B
23	20	14	11	10	6	20	22	23

Size of Plot, 16 Trees.
Treatments:—A—Control.
B—1½ lb. Superphosphate per tree.
C—3 lb. Superphosphate per tree.

Table V.

Rio Claro I. Phosphate Experiment. Analysis of Variance of Yields in No. of Pods per Tree for Combined Crops, 1933, 1934 and 1935.

Due to	D.F.	S.S.	V.	Log_e.	½ Log_e.	Calculated "Z"	Observed "Z" 1 : 20
Total (*a*)	8	2411	—	—	—	—	—
Rows	2	663	—	—	—	—	—
Columns	2	366	—	—	—	—	—
Treatments	2	1319	659	6.4908	3.2454	1.5284	1.4722
Error (*a*)	2	63	31	3.4340	1.7170	—	—
Total (*b*)	26	3221	—	—	—	—	—
Seasons	2	600	300	—	—	—	0.9690
Interaction							
Season × Treatment	4	129	32	3.4660	1.7330	1.1066	0.9272
Season × Rows	4	45	—	—	—	—	—
Season × Columns	4	22	—	—	—	—	—
Error (*b*)	4	14	3.5	1.2528	0.6264	—	—

In order to demonstrate a significant effect, the calculated value of "Z" must exceed the observed value of "Z".

Table VI.

Rio Claro I. Phosphate Experiment.

COMBINED YIELDS FOR 1933, 1934, 1935. PODS PER TREE.

Treatment.	Mean Yield 1933.	Mean Yield 1934.	Mean Yield 1935.	General Mean.
A	16	7	15	**13**
B	31	20	33	**28**
C	24	22	34	**27**

Each yield value in Table VI for any one year is the mean of three plots. The Standard Error of the difference between two yearly means is 1.53; and a difference of 4.3 pods per tree may be considered significant with a minimum probability of 20 : 1.

Table VII.

Rio Claro II. Phosphate Experiment.

COMBINED YIELDS FOR 1933, 1934 AND 1935. PODS PER TREE.

Treatment.	Mean Yield 1933.	Mean Yield 1934.	Mean Yield 1935.	General Mean.
A	18	9	17	**15**
B	15	10	21	**15**
C	17	8	20	**15**

(1) The 1935 crop records confirm the findings already reported for this area. On the Princes Town Marl (black calcareous) Soil, significant increases in yield (*more than* 100 *per cent.*) have

Table VIII.

Las Hermanas II. Phosphate Experiment. Individual Plot Yields. Weight of Wet Cacao (lb.).

EXPERIMENTAL YEAR, 1935.

C 39	B 42	A 50	E 64	D 56
E 48	D 24	B 58	C 66	A 51
D 53	E 51	C 73	A 50	B 60
A 58	C 77	D 54	B 74	E 44
B 85	A 54	E 92	D 42	C 54

PREVIOUS YEAR, 1934.

C 12	B 16	A 13	E 26	D 28
E 12	D 13	B 16	C 21	A 19
D 18	E 8	C 12	A 15	B 20
A 21	C 15	D 16	B 12	E 10
B 18	A 9	E 21	D 15	C 9

Experimental Yields *minus* Previous Yields: 1935-1934.

C 27	B 26	A 37	E 38	D 28
E 36	D 11	B 42	C 45	A 32
D 35	E 43	C 61	A 35	B 40
A 37	C 62	D 38	B 62	E 34
B 67	A 45	E 71	D 27	C 45

Treatments :—A—2 lb. Rock Phosphate per tree.

B—2 lb. Rock Phosphate *plus* 1½ lb. Potassium Sulphate per tree.

C—2 lb. Superphosphate *plus* 1½ lb. Potassium Sulphate per tree.

D—Control.

E—2 lb. Superphosphate per tree.

been obtained from the application of superphosphate manure alone. The increased yield has averaged 15 pods per tree, or approximately 450 lb. dry cacao per acre per annum over a period of three years. There is little difference in yield between plots receiving 3 lb. superphosphate per tree and those receiving 1½ lb. per tree. Recommendations for manuring this soil type are given in the Fourth Annual Report on Cacao Research.

(2) On the Green Clay (gypseous) Soil, there has been no increase in yield due to manuring with superphosphate. The relationship between gypseous soils, the growth of cacao trees, and phosphate manuring was discussed in the Fourth Annual Report.

SERIES II.—EXPERIMENTS WITH DIFFERENT PHOSPHATE MANURES.

(I) Las Hermanas II.

Soil Type.—Alluvial Clay, acidic in reaction.
Age of Trees.—Thirty to thirty-five years.
System of Replication.—One 5 × 5 Latin Square.
Size of Individual Plots.—18 trees.
Treatments :—1—Control.
2—3 lb. rock phosphate per tree.
3—2 lb. rock phosphate *plus* 1½ lb. potassium sulphate per tree.
4—2 lb. superphosphate per tree.
5—2 lb. superphosphate *plus* 1½ lb. potassium sulphate per tree.
Treatment first applied in April, 1934.

Results.—The yield records from 1934 and 1935 are shown in Table VIII. The 1934 yields are for the crop previous to the application of the manures. These natural yields have been used to secure a more accurate interpretation of the results of manuring for the 1935 crop. An analysis of variance has been carried out on the difference between the experimental yields of 1935 and the natural yields of 1934. The summarised results are presented in Table IX.

Table IX.

Las Hermanas II. Phosphate Experiment.

TOTAL YIELDS IN WEIGHT OF WET CACAO.

	1934 (I)	1935 (II)	1935-1934 (III)
TREATMENTS.	Natural Yields.	Experimental Yields.	Experimental Yield *minus* Natural Yields.
	Wt. of Wet Cacao lb.	Wt. of Wet Cacao lb.	Wt. of Wet Cacao lb.
Control	90	229	**139**
Superphosphate	77	299	**222**
Superphosphate *plus* Potash	69	309	**240**
Rock Phosphate	77	263	**186**
Rock Phosphate *plus* Potash	82	319	**237**

Each yield in Table IX is the total yield of five plots. The Standard Error of the difference between two totals in Column (II) is 46.7 lb., and a difference of 102.7 lb. may be regarded as significant with a 20 : 1 probability. The Standard Error of the difference between two totals in Column (III) is 33.9, and a difference of 74.6 lb. may be regarded as significant with a 20 : 1 probability. (N.B.) No significant differences in yield are shown by the 1935 yields alone (Column (II)), but significant differences in yield due to treatments are shown when the 1935 yields are corrected by means of previous records (Column III).

There are considerable differences in the total yields for 1935 from the differently-treated plots, but the erratic variation in the yield of individual plots precludes the possibility of showing that these differences are statistically significant. The use of natural yields from one year's previous records has smoothed out a large part of these erratic variations, and has shown definite differences in yield due to the different manurial treatments. These corrected records show the following significant differences.

(1) Superphosphate manure alone has given a marked increase in yield during the first crop following its application, the increase being statistically significant.

(2) Rock phosphate manure alone has also given a marked increase in yield during the first crop following its application, but the increase is smaller that that due to superphosphate alone, and cannot be considered statistically significant.

(3) Superphosphate *plus* potash, and rock phosphate *plus* potash have given significant increases in yield compared with the control plots. The slightly increased yields due to the addition of potash manure do not differ significantly from the yields due to superphosphate alone or rock phosphate alone.

General Conclusions.—The first year's records from this experiment show increases in yield due to phosphate manuring such as were to be expected from the results of Series I experiments. The chief aim of this experiment is to compare superphosphate with finely-ground raw rock phosphate, and the results indicate a slightly larger immediate increase from the superphosphate treatment. These are only tentative indications, however, since they are based on only one year's records. Past experience has shown that two consecutive crops considered together give a more certain indication of the results of manurial treatments applied to cacao. In the second and subsequent crops after the application of the manures, the full effects due to the slower-acting rock phosphate may become more apparent.

(B) GENERAL MANURIAL EXPERIMENTS.

(1) EXPERIMENTS WITH NITROGEN, PHOSPHATE AND POTASH MANURES ON SHADED AND UNSHADED CULTIVATIONS.

River Estate II and III.

Soil Type.—Alluvial, neutral sandy-silt.
Age of Trees.—Twenty to twenty-five years.
System of Replication.—Two 5 × 5 Latin Squares.
Size of Individual Plots.—22 trees.
Treatments :—1—Control.
2—2 lb. ammonium sulphate per tree
3—2 lb. superphosphate per tree.
4—2 lb. ammonium sulphate *plus* 2 lb. superphosphate per tree.
5—2 lb. ammonium sulphate, *plus* 2 lb. superphosphate *plus* 1½ lb. potassium sulphate per tree.
6—Half-plot.—1½ lb. potassium sulphate per tree.

Considering half-plots, there are nine different treatments represented in the experiment, as follows :—(1) N, (2) P, (3) K, (4) N.P, (5) N.K, (6) P.K, (7) N.P.K, (8) N.P.2K, (9) Control. One square is on fully shaded cultivation, the other square is on cultivation carrying no overhead shade. The manurial treatments were first applied in April, 1934.

Results (a) Crop Yields in Pods per Tree and Weight of Wet Cacao.

The yield records for 1934 and 1935 are presented in Tables X and XI. The 1934 yields are those of the crop previous to the application of the manures. These natural yields have been used to secure a more accurate interpretation of the results of manuring during the 1935 crop. An Analysis of Variance has been carried out on the differences between the experimental yields of 1935 and the natural yields of 1934. The summarised results are presented in Tables XII and XIII.

Table XII.

River Estate. N.P.K. Manurial Experiment.

MEAN YIELDS ; NUMBER OF PODS PER TREE.

TREATMENT.	(I) 1934. NATURAL YIELDS.		(II) 1935. EXPERIMENTAL YIELDS.		(III) 1935 *minus* 1934. CORRECTED EXPT. YIELDS.	
	Field 20 No Shade.	Field 21 Full Shade.	Field 20 No Shade.	Field 21 Full Shade.	Field 20 No Shade.	Field 21 Full Shade.
Control	25.0	18.8	37.4	39.6	**12.4**	**20.8**
N	22.2	19.2	46.0	47.0	**23.8**	**27.8**
P	16.8	19.2	32.2	51.4	**15.4**	**32.2**
K	21.8	12.0	47.6	49.8	**25.8**	**37.8**
NP	22.6	15.8	40.8	56.4	**18.2**	**40.6**
NK	20.0	18.0	56.2	55.6	**36.2**	**37.6**
PK	20.0	16.4	49.6	58.6	**29.6**	**42.2**
NPK	22.6	20.6	52.2	63.1	**29.6**	**42.5**
NP.2K	22.6	18.4	70.8	70.0	**48.2**	**51.6**

Each yield in Table XII is the mean of five half-plots. The Standard Error of the difference between two means in Section III is 6.5, and a difference of 12.7 pods per tree may be considered significant, with a 20 : 1 probability.

Table XIII.

River Estate. N.P.K. Manurial Experiment.

TOTAL YIELDS ; WEIGHT OF WET CACAO (LB.).

TREATMENTS.	(I) 1934. NATURAL YIELDS.		(II) 1935 EXPERIMENTAL YIELDS.		(III) 1935 *minus* 1934 CORRECTED EXPT. YIELDS.	
	Field 20 No Shade.	Field 21 Full Shade.	Field 20 No Shade.	Field 21 Full Shade.	Field 20 No Shade.	Field 21 Full Shade.
Control	245	213	376	436	**131**	**223**
N	236	201	468	471	**232**	**270**
P	175	195	333	501	**158**	**306**
K	221	130	469	505	**248**	**375**
NP	218	163	372	556	**154**	**393**
NK	200	167	479	530	**279**	**363**
PK	194	180	470	616	**276**	**436**
NPK	225	204	482	634	**257**	**430**
NP.2K	232	202	599	723	**367**	**521**

Each yield in Table XIII is the total of five half-plots. The Standard Error of the difference between two means in Column III is 54.1, and a difference between two totals of 106 lb. may be considered significant, with a probability of 20 : 1.

The data contained in Tables XII and XIII indicate the following effects of the different manurial treatments on yield.

(1) In both shaded and unshaded blocks there has been a very large increase in yield due to the application of potash manure, either alone or in combination with nitrogen and phosphate.

(2) The response of the cacao trees to nitrogen and to phosphate appears to be different on the shaded and unshaded block respectively. *There is a bigger response to nitrogen and a smaller response to phosphate on the unshaded block than on the shaded block.*

(3) The greatest increase in yield has been obtained from plots receiving the following manurial mixture :—(Treatment A) :—2 lb. ammonium sulphate, 2 lb. superphosphate and 3 lb. potassium sulphate per tree. The increased yields obtained from this treatment are as follows :—Full shade block, 30.8 pods per tree, or 650 lb. (approximately four bags of 165 lb. each) of dry cacao per acre. No shade block, 35.8 pods per tree, or 514 lb. (approximately three bags of 165 lb. each) of dry cacao per acre.

(4) The total yield from plots receiving treatment A is 70.8 pods per tree for the unshaded block, and 70.0 pods per tree for the shaded block, or 1,308 lb. (eight bags) of dry cacao per acre for the unshaded block and 1,574 lb. (9½ bags) of dry cacao per acre for the shaded block. The smaller weight of cacao obtained from the manured plots on the unshaded block is accounted for, (*a*) by the larger percentage of diseased black pods produced, and (*b*) by the smaller size of pod on the unshaded block. In the next section, the recorded results for pod size and percentage of black pods are presented and discussed.

Table X.

RIVER ESTATE; FIELD 20; NO SHADE. N.P.K. MANURIAL EXPERIMENT; INDIVIDUAL ½ PLOT YIELDS; NUMBER OF PODS PER TREE.

(A)—1934. Natural Yields.

		K		K
33	21	24	17	16
E	B	C	D	A
24	24	34	21	14
K	K		K	
K	K	K		
18	17	10	14	25
B	A	D	E	C
20	11	15	21	18
			K	K
	K		K	
24	26	29	21	17
A	C	E	B	D
28	21	27	13	14
K		K		K
K			K	
26	38	18	20	21
C	D	B	A	E
16	32	24	27	16
	K	K		K
K		K		
39	28	32	15	12
D	E	A	C	B
26	21	34	6	13
	K		K	K

(B)—1935. Experimental Yields.

		K		K
25	34	54	27	58
E	B	C	D	A
58	40	53	44	32
K	K		K	
K	K	K		
46	72	51	36	44
B	A	D	E	C
44	34	42	56	93
			K	K
	K		K	
75	54	48	55	52
A	C	E	B	D
66	42	29	19	72
K		K		K
K			K	
48	47	32	95	34
C	D	B	A	E
46	52	50	46	50
	K	K		K
K		K		
56	44	63	45	32
D	E	A	C	B
36	45	60	32	57
	K		K	K

(C)—1935 *minus* 1934.

		K		K
-8	13	30	10	42
E	B	C	D	A
34	16	19	23	18
K	K		K	
K	K	K		
28	55	41	22	19
B	A	D	E	C
24	23	27	35	75
			K	K
	K		K	
51	28	19	34	35
A	C	E	B	D
38	21	2	6	58
K		K		K
K			K	
22	9	14	75	13
C	D	B	A	E
30	20	26	19	34
	K	K		K
K		K		
17	16	31	30	20
D	E	A	C	B
10	24	26	26	44
	K		K	K

WEIGHT OF WET CACAO (LB.)

		K		K
59	44	52	31	33
E	B	C	D	A
45	53	68	41	26
K	K		K	
K	K	K		
38	31	20	32	50
B	A	D	E	C
41	25	33	45	32
			K	K
	K		K	
52	51	63	32	32
A	C	E	B	D
64	49	61	26	26
K		K		K
K			K	
51	74	38	48	39
C	D	B	A	E
35	66	46	58	32
	K	K		K
K		K		
81	52	56	34	26
D	E	A	C	B
48	38	55	14	25
	K		K	K

		K		K
55	68	113	54	91
E	B	C	D	A
109	91	116	80	53
K	K		K	
K	K	K		
79	126	70	69	79
B	A	D	E	C
85	72	83	103	130
			K	K
	K		K	
140	92	92	93	100
A	C	E	B	D
118	95	58	35	144
K		K		K
K			K	
76	72	68	153	69
C	D	B	A	E
74	90	98	114	112
	K	K		K
K		K		
116	91	111	104	77
D	E	A	C	B
63	87	86	68	109
	K		K	K

		K		K
-4	24	61	23	58
E	B	C	D	A
64	38	48	39	27
K	K		K	
K	K	K		
41	95	50	37	29
B	A	D	E	C
44	47	50	58	98
			K	K
	K		K	
88	41	29	61	68
A	C	E	B	D
54	46	-3	9	118
K		K		K
K			K	
25	-2	30	105	30
C	D	B	A	E
39	24	52	56	80
	K	K		K
K		K		
35	39	55	70	51
D	E	A	C	B
15	49	31	54	84
	K		K	K

Treatments:—A—2 lb. Ammonium Sulphate *plus* 2 lb. Superphosphate *plus* 1½ lb. Potassium Sulphate per tree.
B—2 lb. Superphosphate per tree.
C—2 lb. Ammonium Sulphate per tree.
D—2 lb Ammonium Sulphate *plus* 2 lb. Superphosphate per tree.
E—Control.
Half-plot:—Half of each main plot received 1½ lb. Potassium Sulphate per tree.

Table XI.

River Estate ; Field 21 ; Full Shade. N.P.K. Manurial Experiment ; Individual ½ Plot Yields.

Number of Pods per Tree.

(A)—1934. Natural Yields.

K			K	
23	21	39	10	20
A	D	B	E	C
31	28	22	12	13
	K	K		K
K		K	K	
20	11	18	14	15
D	B	C	A	E
15	12	22	32	10
	K			K
	K		K	K
23	18	30	11	13
C	A	E	B	D
19	17	14	15	12
K		K		
K		K	K	K
14	8	13	13	12
E	C	A	D	B
21	27	13	20	19
	K			
	K			K
12	12	11	23	24
B	E	D	C	A
25	16	14	13	25
K		K	K	

(B)—1935. Experimental Yields

K			K	
79	70	85	27	41
A	D	B	E	C
80	79	71	17	34
	K	K		K
K		K	K	
63	30	61	70	35
D	B	C	A	E
31	59	55	52	45
	K			K
	K		K	K
46	63	63	40	63
C	A	E	B	D
60	49	64	44	35
K		K		
K		K	K	K
63	41	72	56	45
E	C	A	D	B
55	85	68	86	41
	K			
	K			K
57	50	60	52	66
B	E	D	C	A
78	28	55	38	56
K		K	K	

(C)—1935 *minus* 1934.

K			K	
56	49	46	17	21
A	D	B	E	C
49	51	49	5	21
	K	K		K
K		K	K	
43	19	43	56	20
D	B	C	A	E
16	47	33	30	35
	K			K
	K		K	K
23	45	33	29	50
C	A	E	B	D
41	32	50	29	23
K		K		
K		K	K	K
49	33	59	43	33
E	C	A	D	B
34	58	55	66	22
	K			
	K			K
45	38	49	29	42
B	E	D	C	A
53	12	41	25	31
K		K	K	

Weight of wet cacao (lb).

K			K	
55	47	70	24	40
A	D	B	E	C
62	61	46	31	28
	K	K		K
K		K	K	
48	23	40	27	32
D	B	C	A	E
29	29	49	56	21
	K			K
	K			K
50	44	63	23	26
C	A	E	B	D
39	28	31	32	23
K		K		
K		K	K	K
32	18	30	32	28
E	C	A	D	B
47	35	26	38	42
	K			
	K			K
28	22	26	44	46
B	E	D	C	A
54	40	30	25	39
K		K	K	

K			K	
172	133	135	72	92
A	D	B	E	C
148	163	137	67	70
	K	K		K
K		K	K	
154	64	129	129	64
D	B	C	A	E
56	131	111	105	88
	K			K
	K		K	K
85	149	134	80	132
C	A	E	B	D
136	89	118	84	83
K		K		
K		K	K	K
131	77	150	122	99
E	C	A	D	B
104	116	135	157	90
	K			
	K			K
128	96	127	106	123
B	E	D	C	A
169	67	126	79	94
K		K	K	

K			K	
117	86	65	48	52
A	D	B	E	C
86	102	91	36	42
	K	K		K
K		K	K	
106	41	89	102	32
D	B	C	A	E
27	102	62	49	67
	K			K
	K		K	K
35	105	71	57	106
C	A	E	B	D
97	61	87	52	60
K		K		
K		K	K	K
99	59	120	90	71
E	C	A	D	B
57	81	109	119	48
	K			
	K			K
100	74	101	62	77
B	E	D	C	A
115	27	96	54	55
K		K	K	

Treatments :—A—2 lb. Ammonium Sulphate *plus* 2 lb. Superphosphate *plus* 1½ lb. Potassium Sulphate per tree.
B—2 lb. Superphosphate per tree.
C—2 lb. Ammonium Sulphate per tree.
D—2 lb. Ammonium Sulphate *plus* 2 lb. Superphosphate per tree.
E—Control.

Half-Plot :—Half of each main plot received 1½ lb. Potassium Sulphate per tree.

Results (b) Size of Pod and Percentage of Diseased Black Pods.

No previous records of the percentage of black pods are available. During the 1934 crop, diseased black pods were discarded without counting. The size of pod is calculated as the number of pods per pound of dry cacao. The weight of dry cacao is estimated as forty per cent. of the weight of wet cacao. Individual records of the size of pod and of the percentage of black pods are not presented in this report. Detailed examination of these figures will be reserved until experimental yields from two consecutive crops are available. The records for the one crop, 1935, have been summarised, and are presented in Tables XIV and XV.

Table XIV.

River Estate. N.P.K. Manurial Experiment.

MEAN SIZE OF POD. NUMBER OF PODS PER LB. OF DRY CACAO.

TREATMENTS.	(I) 1934 NATURAL YIELDS.		(II) 1935 EXPERIMENTAL YIELDS.		(III) 1935 *minus* 1934. CORRECTED EXPT. YIELDS.	
	Field 20 No Shade.	Field 21 Full Shade.	Field 20 No Shade.	Field 21 Full Shade.	Field 20 No Shade.	Field 21 Full Shade.
Control	1.04	12.1	11.9	11.8	−2.1	−0.3
N	12.7	13.2	11.9	12.1	−0.8	−1.1
P	13.2	13.0	11.5	12.2	−1.7	−0.8
K	13.6	12.5	12.7	12.0	−0.9	−0.5
NP	14.3	13.6	13.1	12.0	−1.2	−1.6
NK	13.9	14.8	13.7	12.7	−0.2	−2.1
PK	14.4	12.5	13.3	11.7	−1.1	−0.8
NPK	13.7	13.9	13.1	12.4	−0.6	−1.5
NP.2K	13.5	12.6	14.5	12.3	+1.0	−0.3
General Average	13.7	13.1	12.9	12.1	−0.8	−1.0

Table XV.

River Estate. N.P.K. Manurial Experiment.

MEAN PERCENTAGE OF BLACK PODS.

Treatments.	1935.	
	Field 20 No Shade.	Field 21 Full Shade.
	Black Pods %	Black Pods %
Control	12.6	12.2
N	13.6	12.4
P	14.8	11.2
K	9.4	14.6
NP	15.6	13.2
NK	12.8	11.0
PK	8.6	10.6
NPK	13.0	10.2
NP.2K	10.4	8.2
General Mean	12.3	11.5

The results in Tables XIV and XV indicate the following differences, (*a*) between differently treated plots, and (*b*) between the shaded and unshaded blocks respectively.

(1) The average size of pod on the shaded block is slightly larger than on the unshaded block.

(2) There is a slightly smaller percentage of black pods on the shaded block than on the unshaded.

(3) On the unshaded block, increased yields due to manuring have coincided with a decreased size of pod (Table XIV, column III). Thus, plots receiving Treatment A (which gave the biggest increase in yield) require 3.1 more pods per pound of dry cacao than do the control plots. For this block therefore, the increased yield due to manuring seems to be caused entirely by the increased number of pods brought to maturity. The very large increase in number of pods on the manured plot has caused a large increase also in the total weight of cacao obtained, but the large load of pods on the manured trees appears to have caused a reduction in the average size of pod. It will be interesting to ascertain whether or no the records from the next crop confirm this finding. The second application of manures may cause the pod size to be maintained, or even to be increased, in addition to an increased number of pods per tree.

(4) On the shaded block, the size of pod obtained from the manured plot has slightly increased, in addition to the very large number of pods obtained.

General Conclusions.

The results so far obtained from this manurial experiment fall into line with the results of soil investigations in this area, and with the previous results of manuring obtained by Pound and de Verteuil. The most marked effect in increasing yields has been obtained by the use of potash manure. A marked increase due to phosphate and a slight increase due to nitrogen are indicated on the shaded block. On the unshaded block, there is a slight increase due to nitrogen, but phosphate manure appears to have conferred no benefit. *The very striking increases in yield on both blocks may be attributed almost entirely to the increased number of pods brought to maturity by the manured trees.* A slight increase in pod size, caused by manurial treatment of the shaded block, is also indicated. On all the manured plots on this block, the size of pod has at least been maintained at its former value. On the unshaded block, however, the greatly increased number of pods carried by the manured trees appears to have coincided with a slightly decreased size of pod.

Many authorities in Trinidad and elsewhere have contended that the presence of shade trees in cacao cultivations seriously affects the possible benefit of the application of artificial manures, since the Immortel shade trees are voracious feeders,

and may take up a large part of the added manures. The first year's records from this present experiment *provide no evidence to support this view*. Indeed, there has been a slightly better response to manuring on the shaded cultivation than on the unshaded cultivation. Shade trees undoubtedly compete with cacao trees for plant nutrients in the soil, but this disadvantage may well be offset by the more favourable atmospheric environment created by their presence. The evidence certainly suggests that cacao fields carrying a reasonable number of shade trees are in better condition to respond to artificial manures than fields in which no overhead shade occurs, at any rate under the climatic and environmental conditions obtaining in Trinidad. The indicated differences in response to artificial manures between shaded and unshaded cacao cultivation are based on one year's records only, and therefore must be considered with some reserve. Records from two consecutive crops should provide more certain information, and may confirm these tentative findings.

Summary.

(1) Further results of manurial experiments on cacao in Trinidad are presented and discussed.

(2) The continued application of heavy dressings of superphosphate (2 lb. per tree and 3 lb. per tree) annually for three years, appears to be wasteful and definitely in excess of the requirements of cacao trees growing on a phosphate-deficient, acidic clay soil. When a light dressing of superphosphate is applied, additional increases in yield are still obtained after the third consecutive annual application.

(3) Superphosphate manure appears to give a slightly larger *immediate* increase in yield than finely-ground rock phosphate manure applied to an acidic clay soil.

(4) The response of cacao trees to artificial manures applied to a potash-deficient sandy soil has been compared on shaded and on unshaded cultivations respectively. Very large increases in yield are indicated for both shaded and unshaded cultivation caused by the application of potash manure alone and in combination with nitrogen and phosphate, a slightly better response to manuring being obtained on the shaded cultivation. Records for one crop only are available, but these indicate that *the presence of large shade trees in cacao fields need not adversely affect to any appreciable extent the response of the cacao trees to artificial manures.*

PART III.

THE MANGANESE CONTENT OF WEST INDIAN CACAO SOILS.

By J. A. McDonald and G. Rodriguez.

Introduction.

Recent investigations have clearly shown that certain minor elements (for example, manganese, iron, magnesium, boron, sulphur, copper and zinc) may exercise much more important effects on soil fertility in the Tropics than has hitherto been generally recognised. The fact that deficiencies of these minor elements occur in temperate soils indicates the possibility of their even more frequent occurrence in tropical soils which are subjected to the heavy leaching effects of high rainfall.

The part played by the minor elements in soil fertility has been summarised in a recent publication (1) by the Imperial Bureau of Soil Science, which contains an extensive list of references to the literature of the subject. One striking feature of this general review is that many of the effects of deficiencies of minor elements may be prevented or cured by heavy applications of organic manures. Recent soil investigations (2), (3), (4), (5), carried out by the Chemistry Department of this College, have shown the great importance of organic matter in controlling the fertility of cacao soils. The exact manner in which organic matter influences cacao soil fertility has not yet been fully explained, and it is possible that part of its benefit may consist in supplying or rendering available certain minor elements which would otherwise be deficient. The subject thus appears to be of sufficient importance to merit a preliminary examination of a number of typical cacao soils with regard to their content of certain minor elements. Manganese, in particular, may be of significant importance, since numerous instances have been reported elsewhere of nutritional disorders occurring under field conditions caused by manganese deficiency. Thus "grey speck" disease of oats, which has long been known in Europe, is believed by some authorities to be due to manganese deficiency, while investigators in Hawaii attach great importance to manganese in soil in relation to the growth and yield of sugar-cane. The sugar-cane soils of the Florida Everglades provide another striking instance of unproductivity caused by manganese deficiency. Some of these soils gave very large increases in crop yields following the application of small quantities of manganese sulphate (25 to 50 lb. per acre).

Nutritional disorders due to manganese deficiency may occur in plants, even though analysis of the soil shows a total manganese content which appears to be adequate. Most soils contain appreciable quantities of manganese, but, under certain conditions, the manganese

becomes unavailable. It is generally agreed that alkaline soil conditions are conducive to manganese deficiency, but there must be other predisposing causes as well, since not all alkaline soils produce the symptoms. The nature of these other conditions is not so definite, but there is considerable evidence in support of the view that manganese deficiency is prevented by reducing conditions, and encouraged by oxidising conditions, in the soil. The simplest explanation is that manganese-ion is only absorbed by plants in the bivalent form, and is readily oxidised to a higher valency under alkaline conditions.

In the following sections, a preliminary examination has been made of the total manganese content of the top 6-inch layer of a number of typical cacao soils taken from different districts in Trinidad, from Grenada and from Tobago.

Results.

The analytical results are presented in Tables I, II, III and IV. The site numbers refer to the numbers of soil profile pits appearing in soil survey reports (2), (3), (4), (5), issued by the Chemistry Department of the College. The soils have been divided into high-yielding and low-yielding groups, and then sub-divided according to the different soil-types. A "good" cacao soil is arbitrarily defined as one giving yields of over eight bags of dry cacao (one bag equals 165 lb.) per thousand pickets.

(A) Trinidad, Montserrat District (4).

The results in Table I show a generally higher manganese content for "good" soils as contrasted with "bad" soils. The difference between the means is more than three times greater than the standard error of this difference, and is therefore statistically significant. The highest manganese content is found in the Chocolate Soil occurring in the Montserrat District of Trinidad. This finding agrees with previously published results (4), which showed that the parent rock from which the Chocolate Soil is derived has a very high manganese content, compared with other soil-forming rocks occurring in this district. One of the most striking features

Table I.

Manganese Content of Top 6-Inch Layer of West Indian Cacao Soils: Trinidad, Montserrat District.

Good Soils.					Bad Soils.				
Site No.	Soil Type.	Yield Bags Per 1,000 Pickets.	MnO %	Reaction (pH).	Site No.	Soil Type.	Yield Bags Per 1,000 Pickets.	MnO %	Reaction (pH).
8	Chocolate Soil	16	0.29	6.8					
34	Chocolate Soil	13	0.30	7.0					
39	Chocolate Soil	13	0.20	7.0					
6	Chocolate Soil	10	0.28	7.2					
24	Chocolate Soil	9	0.15	7.0					
Av.	Chocolate Soil	**13**	**0.24**	**7.0**					
10	Brasso Clay	14	0.22	7.0	66	Brasso Clay	7	0.03	7.0
31	Brasso Clay	13	0.27	6.5	65	Brasso Clay	7	0.02	5.7
32	Brasso Clay	13	0.09	6.1	5	Brasso Clay	6	0.11	5.7
29	Brasso Clay	9	0.13	6.4	57	Brasso Clay	4	0.02	5.8
44	Brasso Clay	9	0.09	6.7	56	Brasso Clay	3	0.05	7.5
49	Brasso Clay	9	0.06	6.2	12	Brasso Clay	3	0.05	5.4
Av.	Brasso Clay	**11**	**0.14**	**6.5**	Av.	Brasso Clay	**5**	**0.05**	**6.2**
38	Brasso Sand	13	0.11	5.3	15	Brasso Sand	6	0.12	5.6
37	Brasso Sand	12	0.13	6.9	47	Brasso Sand	6	0.05	6.2
23	Brasso Sand	12	0.07	6.9	4	Brasso Sand	6	0.02	4.9
18	Brasso Sand	9	0.07	7.3	43	Brasso Sand	4	0.04	6.4
14	Brasso Sand	9	0.03	5.3	—		—	—	—
Av.	Brasso Sand	**11**	**0.08**	**6.4**	Av.	Brasso Sand	**6**	**0.06**	**5.8**
Av.	**Good Soils**	**11.6**	**0.15**	**6.6**	Av.	**Bad Soils**	**5.4**	**0.05**	**6.0**

Table II.

MANGANESE CONTENT OF TOP 6-INCH LAYER OF WEST INDIAN CACAO SOILS: TRINIDAD, RIO CLARO DISTRICT.

GOOD SOILS.					BAD SOILS.				
Site No.	Soil Type.	Yield Bags Per 1,000 Pickets	MnO %	Reaction (pH).	Site No.	Soil Type.	Yield Bags Per 1,000 Pickets.	MnO %	Reaction (pH).
11	P. Town Marl	15	0.20	6.5	12	P. Town Marl	7	0.17	6.2
5	P. Town Marl	15	0.15	6.2	9A	P. Town Marl	6	0.15	6.8
13	P. Town Marl	12	0.81	6.4					
1	P, Town Marl	11	0.30	6.6	Av.	P. Town Marl	**6.5**	**0.16**	**6.5**
8	P. Town Marl	10	0.28	6.7					
7	P. Town Marl	10	0.21	6.4					
9	P. Town Marl	10	0.12	7.5	6	Green Clay	7	0.18	5.8
13A	P. Town Marl	9	0.49	6.7	14	Green Clay	6	0.18	6.0
					10	Green Clay	6	0.12	6.1
					3	Green Clay	5	0.01	4.9
					4	Green Clay	4	0.07	5.4
Av.	**Good Soils**	**11.5**	**0.32**	**6.7**	Av.	Green Clay	**5.6**	**0.11**	**5.6**
					Av.	**Bad Soils**	**6.0**	**0.13**	**5.9**

Table III.

MANGANESE CONTENT OF TOP 6-INCH LAYER OF WEST INDIAN CACAO SOILS: GRENADA.

GOOD SOILS.					BAD SOILS.				
Site No.	Soil Type.	Yield Bags Per 1,000 Pickets.	MnO %	Reaction (pH).	Site No.	Soil Type.	Yield Bags Per 1,000 Pickets.	MnO %	Reaction (pH).
34	Igneous Lava	16	0.38	8.0	36	Igneous Lava	7	0.49	7.9
35	Igneous Lava	15	0.68	6.8	12	Igneous Lava	7	0.26	5.2
7	Igneous Lava	14	0.52	7.4	31	Igneous Lava	6	0.55	8.0
30	Igneous Lava	12	0.22	6.7	13	Igneous Lava	5	0.13	6.6
6	Igneous Lava	9	0.61	8.0	8	Igneous Lava	3	0.23	7.5
Av.	Igneous Lava	**13.2**	**0.48**	**7.4**	Av.	Igneous Lava	**5.6**	**0.33**	**7.0**
25	Igneous Ash	12	0.45	7.4	22	Igneous Ash	8	0.24	6.6
20	Igneous Ash	11	0.14	7.1	26	Igneous Ash	7	0.20	7.3
19	Igneous Ash	9	0.73	7.4	24	Igneous Ash	5	0.22	7.1
					3	Igneous Ash	4	0.15	7.4
					28	Igneous Ash	3	0.16	5.3
Av.	Igneous Ash	**10.7**	**0.44**	**7.3**	Av.	Igneous Ash	**5.4**	**0.19**	**6.7**
10	Alluvium	22	0.14	7.7					
27	Alluvium	15	0.23	7.0					
Av.	Alluvium	**18.5**	**0.18**	**7.4**					
Av.	**Good Soils**	**13.5**	**0.41**	**7.4**	Av.	**Bad Soils**	**5.5**	**0.26**	**6.8**

Table IV.

MANGANESE CONTENT OF TOP 6-INCH LAYER OF WEST INDIAN CACAO SOILS: TOBAGO.

GOOD SOILS.					BAD SOILS.				
Site No.	Soil Type.	Yield Bags Per 1,000 Pickets	MnO %	Reaction (pH).	Site No.	Soil Type.	Yield Bags Per 1,000 Pickets.	MnO %	Reaction (pH).
1	Schist	15	0.15	7.7	21	Schist	4	0.37	6.7
6	Schist	15	0.15	6.7	2	Schist	4	0.17	6.6
					4	Schist	4	0.16	5.8
Av.	Schist	**15**	**0.15**	**7.2**	Av.	Schist	**4**	**0.23**	**6.4**
15	Alluvial	30	0.17	6.7	30	Igneous	8	0.37	6.8
17	Alluvial	20	0.15	6.8	26	Igneous	8	0.28	6.6
34	Alluvial	20	0.08	6.9	8	Igneous	8	0.25	6.2
14	Alluvial	19	0.20	6.8	22	Igneous	8	0.17	6.4
3	Alluvial	15	0.16	7.0	33	Igneous	3	0.38	6.4
13	Alluvial	15	0.15	6.6					
28	Alluvial	13	0.13	6.4					
16	Alluvial	12	0.17	6.8					
Av.	Alluvial	**15.5**	**0.15**	**6.8**	Av.	Igneous	**7**	**0.29**	**6.5**
					19	Alluvial	8	0.19	7.4
					31	Alluvial	4	0.18	7.5
					Av.	Alluvial	**6**	**0.18**	**7.5**
Av.	**Good Soils**	**15.4**	**0.15**	**6.9**	Av.	**Bad Soils**	**5.9**	**0.25**	**6.7**

of these results is the extremely low manganese content of "bad" Brasso Clay Soil. Hitherto the only definite difference established between "good" and "bad" soils of the Brasso Clay type is that the poorer soils contain large accumulations of calcium sulphate (gypsum) at comparatively shallow depths in the profile. In other respects, the physical and chemical properties of the "bad" soils are very similar, and therefore, their infertility for cacao has been attributed to these gypsum accumulations (4). The present results suggest the possibility that manganese dificiency may also be a factor contributing to the low yield of cacao growing on these soils.

(B) TRINIDAD, RIO CLARO DISTRICT (5).

The better soils of this area have a significantly higher manganese content than the poorer soils. The good cacao soils all fall within one soil type, namely the Princes Town Marl Black Soil, whilst the majority of the bad soils belong to the Green Clay Soil type, which is highly gypseous. A number of the Green Clay soil samples show very low manganese contents, and are comparable in this respect with the poorer type of Brasso Clay soil.

(C) GRENADA (3).

Good cacao soils in Grenada (Table III) also have a generally higher manganese content than the bad soils, but the results are more irregular. A number of the "bad" soils, particularly those derived from igneous lava, have high manganese contents, and none of the soils shows an extremely low value, such as is found in the Brasso Clay Soil or the Green Clay Soil in Trinidad. Soils derived from igneous lava in Grenada have the highest, and alluvial soils the lowest manganese content.

(D) TOBAGO (2).

The high-yielding cacao soils examined in Tobago have a significantly *lower* manganese content than the low-yielding soils. This result is somewhat surprising in view of the results obtained for Trinidad and Grenada, but many explanations may be offered of the apparent discrepancy. None of the Tobago soils, good or bad, shows an exceptionally low manganese content, such as would suggest the possibility of manganese deficiency. The majority of good soils selected for examination happen to be alluvial soils situated in a well- watered sheltered environment, whilst the bad soils have been derived from metamorphic schist or igneous rock located on steep hillsides. The regular differences obtained may therefore be merely an indication of the different manganese contents of two entirely different types of soil, and may provide no guide to the relative productivity of the cacao soils of Tobago. In support of this view, it should be

noted that the alluvial soils examined in Grenada show a very high yield, but they also have a comparatively low manganese content.

General Conclusions.

The summarised results indicate a definite and regular difference between the manganese content of different types of West Indian cacao soils. Soils derived from calcareous sedimentary rocks and igneous rocks contain more manganese in the surface layers than soils derived from non-calcareous sediments and recent alluvium. From the present evidence it is difficult to decide whether or no soil manganese is definitely associated with the productivity of cacao soils. Within the same soil-type, and under similar environmental conditions, high-yielding soils appear to have a higher manganese content than low-yielding soils, but the Tobago results demonstrate that this generalisation cannot invariably be applied. It is recognised that the total manganese content of a soil gives only a very rough estimate of the amount of manganese available to the plant, and therefore the present results can only provide a very broad indication of the manganese status of these cacao soils and of the possible influence of manganese on productivity.

Spectroscopic Examination of Cacao Leaf Material.

The most interesting results are yielded by comparison of the manganese contents of gypseous clay soils and of other clay soils. The results suggest that *manganese deficiency may be a factor contributing to the low yield of cacao growing on gypseous clay soils in Trinidad.* This theory is supported by results of the spectroscopic examination of cacao leaf material* carried out by Dr. Judd Lewis in London, on leaf samples provided by this Department. These analyses show that cacao leaves taken from a non-gypseous alluvial clay soil (Las Hermanas Estate) contain approximately 24 times the quantity of manganese found in leaves from cacao trees growing on a highly gypseous Brasso Clay soil (Santa Serviera Estate, No. 66, Table I), now shown to have a very low manganese content.

Lack of Response of Gypseous Soils to Phosphate Manuring.

One of the peculiarities of gypseous cacao soils in Trinidad is their failure to respond to phosphate manuring (6), even though their available phosphate status may be as low as, or lower than the phosphate status of other clay soils which have given immediate large increases in yield following the application of phosphatic manure. The two sets of leaf samples examined by Dr. Judd Lewis were actually taken from the sites of two phosphate manurial experiments (6). On the non-gypseous alluvial clay (Las Hermanas Estate), an increased yield of cacao of approximately one hundred per cent. was obtained, while on the gypseous clay (Santa Serviera Estate), no increased yield due to phosphate manuring could be detected (6). Manganese deficiency may therefore be involved in the failure of these gypseous soils to respond to phosphate manuring. It has been reported elsewhere (7) that certain manganese-deficient Coastal Plains soils of the United States of America, fail to respond to phosphate manuring, even though the soil contains very small amounts of available phosphate. A new line of attack is thus suggested on this somewhat puzzling problem concerning the low yield of cacao trees growing on gypseous soils. A field experiment has already been initiated in order to test the effect of added gypsum on the phosphate uptake and yield of cacao (6). The present results certainly suggest that a field trial should be made of the effects of adding small quantities of manganese sulphate (with and without phosphate) to low-yielding gypseous cacao soils.

* Private Communication, not published.

Summary.

(1) A preliminary examination has been made of the manganese status of typical West Indian cacao soils.

(2) Soils derived from calcareous sedimentary rocks and from igneous rocks contain a larger amount of manganese in their surface layers than soils derived from non-calcareous sediments and from recent alluvium.

(3) Manganese deficiency appears to be a factor contributing to the low yield of cacao growing on certain gypseous clay soils in Trinidad. The low manganese content of these soils may also be involved in their failure to respond to phosphatic manures.

(4) The evidence on these points, based on soil analysis, is by no means conclusive, but it is supported by the results of spectroscopic analysis of cacao leaf material. The application of small quantities of manganese sulphate to gypseous clay soils is recommended for trial by field experiments.

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PART IV.

A NEW METHOD OF CURING SMALL QUANTITIES OF CACAO.

By J. A. McDonald.
(*Chemist for Cacao Research*).

(I) Introduction.

(*a*) *Cacao Fermentation.*

The process of fermentation or sweating is the recognised method of preparing fresh cacao beans for the market throughout the cacao-producing countries of the world. Cacao fermentation is an old process, evolved in the first place by planters without any scientific knowledge. During recent years, however, a large number of scientific workers in different parts of the world have investigated the problem, and there is now an extensive literature on the subject of the preparation or curing of cacao between picking in the field and marketing. Recent comprehensive reviews of the subject have been published by Knapp (1) and by Briton-Jones (2). They conclude that scientific investigators have not yet devised a method which gives a final product of such good all-round quality as the traditional methods of fermentation.

There is no doubt that fermentation greatly improves the quality of cacao from the point of view of the manufacturers, who are prepared to pay a substantial premium in price for properly fermented cacao. The effects of fermentation on the quality of the cacao bean, and the respective properties of fermented and unfermented cacao, have been the subjects of a great many articles in commercial and sicentific journals during recent years. These subjects, therefore, will only receive brief mention in this article. The chief objects of fermentation are as follows:— (1) Killing the bean, thereby making it possible for other important biochemical changes to be brought about, (2) Removal of the pulp, thereby facilitating subsequent drying, and (3) Dissociation of the cotyledons from the seed-coat or testa, thereby facilitating their extraction as nibs on roasting. The important changes mentioned under (1) include desirable changes in colour, aroma, taste and consistency of the bean. The exact manner in which these changes occur during fermentation has not yet been explained, but most investigators agree that the high temperatures produced by the microorganic activity in the fermenting mass of beans is of paramount importance. Indeed, these high temperatures are considered by many authorities to be the essential feature of the process. The rise in temperature is sufficient to cause the death of the bean without harming the enzymes which are essential for carrying out the biochemical changes that produce the desirable properties found in fermented cacao. The death of the bean increases the permeability of the cells of the cacao embryo, thereby permitting free intermixture of their contents, and allowing the oxidative transformation of tannins to proceed.

Attempts to produce the results of natural fermentation by subjecting fresh ripe cacao beans to simple heating, have been made at various times, notably by Fickendey (3) and by Stevens (4). Stevens showed that exposure of cacao beans to temperatures from 113°F. to 140°F. (45°C. to 60°C.) for several days killed the embryo without destroying the enzymes, and resulted in the desired colour changes in the embryo. Concerning these heat-treated beans, Stevens reported that "Allegretti's cacao buyer priced them at a much higher figure, varying from one to three cents a pound, due to their superior colour, aroma and lack of acidity". Knapp, however, states that, whilst the desirable colour changes are produced by the Stevens' heat treatment, the roasted beans lack the full chocolate flavour and odour of fermented cacao. Further, the heat treatment is not sufficiently easy of application, and takes no account of the economic aspect of the removal of the pulp. Stevens' experiments were carried out in 1925, but, so far as the writer is aware, no attempt has been made to put the method into commercial practice up to the present date.

(*b*) *Fermentation of Small Quantities of Cacao.*

The difficulty of obtaining a satisfactory product when small lots of wet cacao are fermented is well recognised. The trouble arises through the large area of surface exposed in relation to the volume of the mass, so that too much cooling occurs, and the high temperatures requisite for the killing of the embryo are never attained. A small bulk of cacao is also apt to dry out too quickly. The net result is that the majority of the beans are unfermented, or only partially fermented; many are germinated, and those occurring at the edges are dried up and shrivelled, or may be covered with moulds. The crux of the problem therefore appears to be the protection of small quantities of cacao from excessive cooling and evaporation; if this can be done effectively and cheaply, then there is no reason why a good quality product should not be obtained. Knapp has given the following directions for fermenting small quantities of cacao. "When fermenting small quantities, such as would produce 50 to 100 lb. of dry beans, they should be placed in a box which they almost fill. The box must be first lined, and the beans well covered with banana leaves. The box should be placed in another box somewhat larger, and prevented from touching the bottom by resting on logs. The outer box should also be similarly raised, and both boxes should be perforated at the bottom to allow the sweatings to escape. The whole may be covered by a loose fitting lid, and may be freely exposed to the sunlight to keep warm. Small quantities

are apt to dry up before fermentation sets in, so that the first two days' sweatings should be collected in a clean vessel and sprinkled over the beans. After the first two days, the beans should be emptied into the larger box, mixed and put back into the smaller box. This should be repeated each day ".

The heat treatment of Stevens also suggests itself as a possible method of curing small quantities of cacao, since it is only with small quantities that insufficient heat is naturally and cheaply produced by the fermenting mass. Furthermore, an artificial supply of heat could more easily be applied to small quantities than to large amounts, such as are generally used under estate conditions. To sum up, natural fermentation is not a satisfactory method of curing small quantities of raw cacao, and simple heat treatment is impracticable for various economic reasons. The ideal method therefore would appear to be one which combines the advantages of the two methods, and one which largely eliminates their disadvantages.

The writer has recently devised a fermenting frame which possesses the following advantages, (1) a blanket of warm air at a temperature ranging from 100°F. to 150°F. (38°C. to 65°C.) is maintained round the sweat box for a period of eight hours in the day, (2) a humid atmosphere can be maintained round the sweat box, thus preventing excessive evaporation, (3) the apparatus required is simply constructed, and the first cost is comparatively low, (4) the source of heat costs nothing. Details concerning the design and construction of this experimental fermenting frame are given in the following section.

(II) The Solar Fermenting Frame for Curing Small Quantities of Cacao.

In most tropical countries where cacao is grown the sun is a constant and reliable source of heat throughout the day-time. In Trinidad, there is an average of six to eight hours of bright sunshine each day during the eight months in which the bulk of the cacao crop is picked. The temperature of dark-coloured objects exposed to direct sunlight and adequately insulated reaches an average maximum temperature of 150°F. or 65°C. In considering possible methods of curing small quantities of cacao, it seemed feasible to utilise this cheap and constant source of heat for producing temperatures whose range lies almost exactly within the limits stated by Stevens to be necessary for killing the beans without destroying the enzymes. A simple adoption of the greenhouse or solar propagation principle to the construction of a fermenting frame enables sunlight to be used for heating the mass of fermenting cacao beans. The first experimental frame constructed on this principle consists of a double-walled, double-bottomed wooden frame or cabinet of external measurements, 6 ft. by 4 ft. by 4 ft., a 3-inch air space being left all round between the inner and outer walls. This air space was subsequently packed with straw to provide more efficient insulation. The frame is painted black, inside and out, and is provided with a moveable glass-paned cover. Two wooden planks, fixed on edge along the bottom of the frame, support separate moveable sweat-boxes at a height of eight inches above the bottom of the frame. Two sizes of sweat-box were made, (*a*) 1 ft. by 1 ft. by 1 ft., and (*b*) 1 ft. by 1 ft. by 1½ ft. internal dimensions. The individual sweat boxes are provided with a lid which fits over and completely encloses the sweat-box, leaving a space of half an inch between box and lid. The bottom and sides of the sweat-boxes are perforated, but the top only of the lid is perforated. Boxes and lids are painted black on the outside only.

In theory, the solariser frame should provide ideal conditions for the fermentation of small quantities of cacao. Heat energy in the form of sunlight, passing through the glass cover, strikes the blackened walls and floor of the frame ; the black surface absorbs the heat, and warms the air in contact with it, thus producing an envelope of hot air which is retained by the glass cover and completely surrounds the sweat-boxes. Cacao treated by this method is therefore cured by a combination of natural fermentation and the heat treatment. Cacao beans are placed in the sweat-boxes and allowed to ferment in the normal manner, but the envelope of hot air surrounding the sweat-boxes prevents the escape of heat produced by fermentation, and some heat is actually supplied to the fermenting beans during the hottest hours of the day. By enclosing some wet sacking or wetting the walls and floor of the frame, the air inside may be kept moist as well as hot, thereby preventing excessive drying of the small mass of cacao.

As indicated by the dimensions of the sweat-boxes, the preliminary experiments were carried out with very small quantities of wet cacao. The smaller boxes hold about 40 lb., and the larger boxes 60 lb. of wet cacao. As far as the writer is aware, no definite attempts have been made previously to ferment such small quantities of cacao. (Knapp refers to small quantities as those which would produce 50 lb. to 100 lb. of dry beans, *i.e.*, 125 lb. to 250 lb. of wet cacao.) It was thought that the curing of such very small quantities would present the greatest difficulties, and would therefore be most useful in revealing those features of the method which might require modification. If conditions might be so adjusted that a final product of good quality is obtained with lots of 40 lb. to 60 lb. of wet cacao, then no difficulty should be experienced with larger amounts.

(III) Temperature and Humidity of Air inside the Solar Fermenting Frame.

Before carrying out definite fermentation trials, preliminary records were taken of air temperature and humidity inside the empty frame. The results are presented in Table I.

Table I.

TEMPERATURE AND HUMIDITY OF AIR INSIDE CACAO SOLAR FERMENTING FRAME UNDER VARYING CONDITIONS OF MOISTURE: COMPARISON WITH EXTERNAL ENVIRONMENTAL CONDITIONS.

	CONDITION OF AIR IN ENCLOSED GLASS-COVERED FRAME.								METEOROLOGICAL DATA FOR COMPARABLE PERIODS.									
	Temperature (°F.)			Rel. Humidity (%)			Satn. Def. Millibars	Evap. cc. per 24 hrs.	Sunshine Hrs. per day	Rain ins. per Day.	Wind m.p.h. Mean.	Shade Temerature (°F.)			Rel. Humidity (%).			Satn. Def. Millibars.	Evap. cc. per 24 hrs.
	Max.	Min.	Mean.	Max.	Min.	Mean.						Max.	Min.	Mean.	Max.	Min.	Mean.		
Natural conditions in empty frame Two-day period	155	72	110	75	26	53	41	61	7.4	0.00	2.8	84	68	77.4	99	64	86	5	34
Small bowl full of water enclosed in Frame. Two-day period	160	70	109	80	24	58	37	59	8.6	0.04	2.5	85	63	75.0	99	55	82	6	38
Floor, walls and straw packing of frame thoroughly wetted before closing. Three-day period	148	70	108	99	39	79	18	27	9.0	0.02	2.4	84	63	75.2	99	55	83	6	39

(*a*) *Temperature.*

The records show that the temperature of the air inside the frame may reach a maximum of 160°F. (71°C.), averaging 70° to 75°F. higher than the maximum temperature of air outside. The air inside the frame is subject to excessive cooling at night, and the maximum temperature in the frame is only 4° to 7°F. higher than that of the air outside. The net result is that the air inside the frame shows an average temperature throughout the 24 hours 33°F. higher than that of the outside air.

(*b*) *Humidity.*

When no precautions are taken to conserve humidity inside the frame, the air becomes very dry. The minimum daily relative humidity falls to a value of about 25 per cent. as compared with 65 per cent. for the outside air. These very dry conditions are to be expected in view of the high temperatures attained by the air inside the frame. As the temperature of the air increases, its ability to hold moisture increases, and unless additional moisture is supplied, the margin between its saturation point and the actual moisture content increases rapidly, thus producing very dry air with a very high evaporating ability. The mean saturation deficit of the air gives a measure of its evaporating ability, and the saturation deficit of the air inside the frame is approximately eight times greater than that of the outside air. The actual rate of evaporation inside the frame is not, however, proportional to its very large saturation deficit. Measurements made with Livingston atmometers show that the actual rate of evaporation inside the frame is only 80 per cent. more than that of the outside air. This is due to the greater amount of movement of the outside air, which greatly increases the rate of evaporation compared with the still air inside the frame.

An attempt was made to supply moisture to the air inside the frame by enclosing a small bowl of water. The results in section (2) of Table I show that this device produced very little effect. Evidently the amount of evaporation from the limited water surface was not sufficient to offset the rapid rise of temperature of the air during the day time.

A further attempt was consequently made to humidify the air inside the frame by the following procedures. Water was poured between the double walls of the frame so as to saturate the straw packing; wet sacks were placed on the bottom, and the inside walls and floor of the frame were thoroughly wetted before closing with the glass cover. The results contained in section (3)

of Table I indicate that these procedures had the effect of reducing the maximum temperature attained in the frame by about 7°F., but a very great increase in the humidity of the air was obtained. Under these conditions, the mean relative humidity of the air inside the frame was approximately the same as that of the outside air. The minimum humidity inside the frame during the time of maximum temperature, was considerably lower than that of the outside air, but this dry period was only of very short duration. Over a period of two weeks, the air inside the frame was maintained at or near saturation point for a period of 13 hours out of every 24, compared with an average saturated period of eight hours out of 24 for the outside air. The average rate of evaporation during 24 hours inside the frame was approximately 70 per cent. of that of the outside air. In order to maintain these desirable humid conditions inside the frame, it was found necessary to wet thoroughly the floor and walls of the frame *every day*. This operation is best carried out in the morning, within one or two hours of sunrise, since at this period, the temperature of the air inside the frame is lowest, and differs only slightly from that of the outside air. The amount of heat lost by removing the glass cover is therefore negligible at this time of day.

(IV) Fermentation Trials.

The cacao used in the fermentation experiments was a low quality Trinidad cacao in which the Calabacillo type predominated. Under estate conditions, this type of cacao is usually fermented for about ten days, but with very small quantities, an even longer period of fermentation might be necessary. A Calabacillo type of cacao was deliberately selected for these experiments, since it is a type of cacao that requires very thorough fermentation if a good quality final product is to be obtained. Experiments carried out with Calabacillo cacao should therefore provide a thorough test of the merits of the new method of fermentation.

(A) Lot I.

The first trial consisted of 40 lb. of fresh, ripe cacao beans placed in the smaller size of sweat-box, and fermented inside the closed frame for a period of nine days. No precautions were taken to humidify the air inside the frame, nor to prevent excessive evaporation from the wet cacao. After nine days in the sweat-box, the beans showed none of the characteristics of fermented cacao; they were flat and shrivelled, the shell was soft, leathery and tightly adhering, and the texture of the kernel cheesy, and its colour dull slate or dark purple. After drying, the beans had the appearance of cacao that has been sun-dried without previous fermentation. It was evident that the extremely dry conditions inside the frame had so desiccated the mass of cacao that scarcely any fermentation had taken place. None of the beans was germinated, so it was evident that the high temperature had killed the embryo soon after the beans were put into the frame. This first preliminary trial emphasized the necessity for maintaining a humid environment round the small mass of cacao, and thus preventing excessive evaporation.

(B) Lot II.

In this second trial, a comparison was made between a 40 lb. batch of fresh cacao fermented inside the special frame, and a similar 40 lb. batch fermented under normal conditions outside. The sweat-boxes used for both lots were of identical construction (as described in Section II). Both boxes were well lined with banana leaves before the wet cacao was introduced. The outside box was placed in a position where it was sheltered from the wind, but was exposed to full sunlight, so that its black outer surface could absorb as much heat as possible during the day time. A piece of black waterproof paper placed loosely over the top served to keep out rain. At night, the outside box was covered with sacking to prevent excessive cooling. Every effort was thus made to produce favourable conditions for a successful fermentation in the outside box. Inside the frame, an attempt was made to maintain a humid atmosphere by enclosing a small bowl of water. The fermentation was carried on for 11 days, and during this period, neither box was moved, no effort being made to carry out periodic turning in either case.

Temperature Fluctuations; Lot II.

Continuous records of the temperature of the centre of each mass were taken throughout the fermentation period with a Negretti and Zambra mercury-in-steel distance recording thermometer. The records are summarised in Table II.

Table II.

Fermentation Temperatures of 40 lb. Wet Cacao in Solar Frame Compared with Ordinary Conditions.

No. of Days in Sweat-Box.	Sweat-Box Inside Solar Frame.			Sweat-Box Under Ordinary Conditions Outside.		
	Max. °F.	Min. °F.	Mean °F.	Max. °F.	Min. °F.	Mean °F.
1	91	80	85	81	80	80
2	111	106	108	91	89	90
3	121	106	113	101	100	100
4	122	106	114	110	106	108
5	124	104	114	110	105	108
6	114	111	113	110	108	109
7	120	107	113	110	108	109
8	119	109	114	110	108	109
9	124	106	115	110	108	109
10	119	104	112	109	105	107
11	119	105	112	110	105	107
Averages	117	104	110	105	102	103

The records in Table II show that the maximum temperature of the cacao inside the frame quickly rose to over 120°F. on the third day. The maximum temperature in the box outside under normal conditions never rose above 110°F., and this temperature was not attained until the fourth day. On the sixth day, cloudy weather prevailed, and the maximum temperature of the cacao inside the frame differed only slightly from the maximum temperature of the cacao outside. After the third day, minimum temperatures of the cacao inside the frame were similar to those outside, but sometimes fell lower. The general results show that the frame had the desired effect in that temperatures exceeding 113°F. were exceeded and maintained for several hours each day in this very small amount of fermenting cacao. Without the protection and additional heat provided by the frame, a similar small amount of cacao never attained the desired temperature of 113°F. Nevertheless, in its present form, the frame does not appear to give adequate protection against cooling at night.

Appearance of Fermented Cacao before Drying; Lot II.

After eleven days' fermentation, the cacao inside the frame appeared to be well fermented. The beans were round and plump and full of juice. Their colour was dark brown externally and pale or dark brown internally. The testas were loose, and the kernels crumbled easily. A few beans situated on the edges of the bulk were slightly dried and shrivelled, but, compared with Lot I, the packing of banana leaves seemed to have provided adequate protection against excessive evaporation. There was no noticeable growth of mould. The fermented cacao was collected for drying in two samples, a thin layer from the edges containing partially dry or shrivelled beans being collected separately from the centre.

After eleven days' fermentation, the cacao in the outside box differed greatly in appearance from the cacao inside the frame. Beans from the centre of the mass appeared to be well fermented, and nearly equal in external and internal appearance to those from inside the frame. The beans at the edges of the mass, however, were covered with a thick growth of mould, and a large number of them were dry and shrivelled. The mouldy beans were black externally, and had an unpleasant odour. The mouldy and dried beans from the edges were collected separately from the central beans.

Appearance of Cured Cacao after Sun-drying and Dancing; Lots I and II.

In order to obtain an independent and completely unbiased estimate of the relative commercial value of the different samples, they were submitted for criticism to a large firm of cacao dealers in Port-of-Spain. A sample of cacao beans from the same picking, sweated and dried under estate conditions, was also submitted at the same time for comparative purposes. The dealers reported as follows :—

Dealers' Report on Lots I and II.

Sample A.—Lot. I, 40 lb. wet cacao gave 14½ lb. dry cacao. Fermented nine days in solar frame. No attempt to secure humid atmosphere. Sweat-box not lined with banana leaves. "This sample is unfermented cacao, commercially known as Ordinary. It is greyish from want of dancing and manipulation, and could be improved if this process was adopted. Value, about $6.00 per fanega (110 lb.)."

Sample B.—Lot II. 40 lb. wet cacao gave 15 lb. dry cacao. Fermented 11 days in solar frame. Bowl of water enclosed in frame to secure humid atmosphere. Sweat-box carefully lined with banana leaves. Sample B is central portion (12 lb. dry wt.), excluding surface layers which partially dried out during fermentation.

" Best sample of the lot, fairly well fermented, fair break, but can be improved with better manipulation. Value $6.75 per fanega."

Sample C.—Lot II. 40 lb. wet cacao gave 15 lb. dry cacao. Fermented 11 days under ordinary conditions. Sweat-box carefully lined with banana leaves. Sample C is the central portion of mould-free cacao (9 lb. dry weight). " Well fermented with good break, but also needs better manipulation, which would greatly add to appearance and value. Value $6.70 per fanega.'

Sample D.—Lot II. Surface layers from (B). Beans which partially dried out during fermentation (3 lb. dry weight). " Fairly well fermented, but not as good break as Sample C. Also needs better manipulation. Value, $6.70 per fanega."

Sample E.—Lot II. Surface layers from (C). Mouldy beans and beans which partially dried out drying fermentation (6 lb. dry weight).

" Known as weathered cacao, good break, but all fat and commercial matter lost. Value, $6.00 per fanega."

Sample F.—Estate cacao from same picking as Lot II, fermented nine days under estate conditions in lots of 2,000 lb. wet cacao.

" Needs better fermentation, break irregular, but outward appearance better than any. Value $6.70 per fanega."

By means of the special glass-covered solar fermenting frame it is evidently possible to produce a good quality fermented cacao from lots of wet cacao as small as 40 lb. weight. The only adverse criticism, compared with that of estate cacao, is that the beans require better " manipulation " *i.e.*, dancing and polishing during the drying process. The final products of 15 lb. dried fermented beans is equal in appearance and value on the local market to cacao fermented and dried

under estate conditions in lots of 1,000 lb. to 2,000 lb. wet cacao. The low value of cacao fermented in such small lots under ordinary conditions is evidently due chiefly to the poor quality of the surface portions of the fermenting mass. Under conditions inside the solar fermenting frame, the surface portions are nearly as good as the centre, thus giving a more even sample of much better all round quality.

(C) Lot III.

Experiments under this heading were carried out with the larger size of sweat-box, containing 60 lb. wet cacao. Two 60 lb. lots were compared, as before, one inside the solar frame and another outside under ordinary conditions. The outside box was exposed to sunlight and protected from wind, rain and excessive cooling at night. Inside the frame, a humid atmosphere was maintained round the sweat-box by means of wet sacking and wetting the walls and floor of the frame as described in Section III. Both sweat-boxes were lined with banana leaves before introducing the wet cacao. The fermentation was allowed to proceed for 13 days, and during this period, neither box was moved, no effort being made to carry out periodic turning in either case.

Temperature Fluctuations. Lot III.

Continuous records of the temperature of the centre and bottom edge of each mass of fermenting cacao were taken throughout the fermentation period. The temperature records are presented in Table III.

Maximum temperatures in the centre of the cacao mass inside the frame rose rapidly to 115°F. on the fourth day, and were maintained between 115°F. and 120°F. until the tenth day. Maximum temperatures of the bottom corner of the mass were very similar to those of the centre, being on an average 1°F. higher per day.

In the outside box, the maximum temperature of the centre never rose above 110°F. which was attained on the seventh day. The maximum temperature of the bottom corner never rose above 108°F., also attained on the seventh day, while minimum temperatures of the bottom corner averaged 10°F. less than those of the centre during the whole fermentation period. The difference between the maximum temperature of the centre of the mass inside the frame and the maximum temperature of the centre of the outside mass is slightly less than in the Lot II trial. This is probably due to the reduction in the maximum temperature of the air inside the frame, caused by the procedure for humidifying the air in Lot III (see Table I). An important feature of these records is the comparative difference between centre and edge temperatures. Inside the frame, the mean temperature of the bottom corner of the fermenting mass is the same as that of the centre. In the outside box, the mean temperature of the bottom corner is 6°F. lower than that of the centre.

Appearance of Fermented Cacao before Drying; Lot III.

The fermented cacao from the box inside the solar fermenting frame was of excellent appearance. There were no patches of mould, and even the

Table III.

Fermentation Temperatures of 60 lb. Wet Cacao in Solar Frame Compared with Ordinary Conditions.

No. of Days in Sweat-Box.	Sweat-Box Inside Solar Frame.						Sweat-Box Under Ordinary Conditions.					
	Centre of Sweat-Box.			Bottom Edge of Sweat-Box.			Centre of Sweat-Box.			Bottom Edge of Sweat-Box.		
	Max. °F.	Min. °F.	Mean °F.	Max. °F.	Min. °F.	Mean °F.	Max. °F.	Min. °F.	Mean °F.	Max. °F.	Min. °F.	Mean °F.
1	94	80	85	89	80	84	85	80	82	84	80	82
2	106	94	100	106	98	101	94	93	94	90	86	88
3	108	96	103	108	98	101	98	96	97	95	89	92
4	115	103	109	114	101	105	106	104	105	102	97	100
5	116	103	110	116	100	106	110	104	107	108	98	103
6	120	100	110	121	98	108	110	104	107	109	96	102
7	117	104	110	118	100	107	111	106	108	108	96	102
8	116	103	110	118	98	106	110	105	107	105	94	100
9	116	104	110	116	100	107	110	106	108	105	96	100
10	111	102	107	113	99	104	108	102	105	100	93	96
11	115	102	108	117	100	106	108	104	107	101	96	99
12	111	99	105	113	98	105	109	103	106	102	93	97
13	111	98	105	116	98	105	107	101	104	100	91	96
Averages	112	99	106	113	98	106	105	101	103	101	93	97

beans on the very edge of the mass were plump and juicy, and of good internal and external appearance. The number of dried and shrivelled beans was negligible, and it was evident that the precautions taken to maintain a humid atmosphere had exercised a very beneficial effect on the final appearance of the surface layers. The fermented, beans were collected for drying in one sample only, since there were no obvious differences between the centre and the edges of the mass.

The cacao beans from the centre of the outside box seemed to be well fermented, and nearly identical in appearance to those from the inside box, but, as in Lot II, there was a thick growth of mould over portions of the surface. The mould had penetrated in patches towards the centre, owing perhaps to the longer period of fermentation in this experiment. One third of the total weight of beans was either black and mouldy with a very bad odour, or partially dried and shrivelled. This portion was collected as a separate sample.

Appearance of Cured Cacao after Sun-Drying and Dancing; Lot III.

The different sample from Lot III, together with a comparable sample of cacao cured under estate conditions, were submitted to a large firm of cacao dealers in Port-of-Spain for criticism and valuation. Their report was as follows:—

Dealers' Report on Lot III.

Sample A.—Lot III. 60 lb. wet cacao gave 23 lb. dry cacao. Fermented 13 days in solar frame. Humid atmosphere maintained by enclosing wet sacking and by wetting walls and floor of frame. Sweat-box lined with banana leaves.

"Very good fermentation, good external appearance, good plump beans, very good break, poor aroma. Value $6.75 per fanega."

Sample B.—Lot III. 60 lb. wet cacao gave 22 lb. dry cacao. Fermented 13 days under ordinary conditions. Sweat-box lined with banana leaves. Sample B is central portion (14 lb. dry weight), excluding obviously mouldy and partially-dried beans from surface layers.

"Good fermentation, poor external appearance shrivelled beans, poor aroma. Value $6.50 per fanega."

Sample C.—Lot III. Surface layers from (B) Obviously mouldy beans and beans which had partially dried during fermentation (7½ lb. dry weight).

"Badly fermented, very bad external appearance, plump beans, good break, no aroma, known as weathered cacao. Value $6.00 per fanega."

Sample D.—Estate cacao from same picking as Lot III fermented nine days under estate conditions in lots of 2,000 lb. wet cacao.

"Irregular fermentation, fairly good external appearance, many flat beans, irregular break, fair aroma. Value $6.50 per fanega."

The dealers' report shows that this small lot of 60 lb. wet cacao has been successfully fermented by treatment in a wooden sweat-box enclosed in the solar fermenting frame. The final product of 23 lb. dried cured cacao beans was better fermented, had a better external and internal appearance, and a higher value on the local market than cured cacao fermented in large lots (1,000 lb. to 2,000 lb. wet weight) under ordinary estate conditions. A similar small lot of 60 lb. wet cacao fermented in a wooden sweat-box under ordinary conditions, gave a final product of very inferior quality and lower value on the local market. The low value was largely due to the inferior quality of the surface layers, which either became mouldy or dried and shrivelled during the fermentation process.

The solar fermenting frame seems therefore to be very effective in producing an even fermentation throughout a small mass of cacao, the surface layers being free from mould, and as well fermented as the central portion. The precautions taken to maintain a humid atmosphere inside the frame during the fermentation period have resulted in an improved appearance and greater value of the final product.

(V) General Conclusions: Possible Practical Applications of the Solar Fermenting Frame.

Interest in the fermentation of separate small quantities of fresh cacao originally arose in connection with certain biochemical investigations which have recently been initiated. These investigations involve the chemical examination of fresh cacao beans taken from small plots receiving different manurial treatments in field experiments. The biochemical examination of different varietal types of cacao is also being undertaken, and this necessitates dealing with very small samples from a few trees or, in certain cases, with a few pods from a single tree. The biochemical effects of fermentation on these different samples is also being studied. An attempt was accordingly made to devise some method for the successful fermentation of such small quantities, whereby the cured dry cacao beans would be comparable in appearance and commercial value with estate cacao fermented in large batches. The practical results of preliminary experiments with the solar fermenting frame have greatly exceeded expectations. The final product obtained from the fermentation of 60 lb. wet cacao was superior in appearance and value on the local market to estate cacao fermented in lots of 1,000 lb. to 2,000 lb. Maximum temperatures attained during fermentation inside the frame were 7°F. to 12°F. higher than the maximum temperatures attained by a similar small mass of cacao fermenting under ordinary favourable conditions outside the frame. One of the most promising features of the method is that it ensures an *even fermentation* in a small mass of cacao. The surface layers are free from mould and as well fermented as the central portion, although no turning was carried out, the mass being left

undisturbed during the whole period of fermentation. Temperature records show that the mean temperature of the bottom corner of the fermenting mass inside the frame is the same as the mean temperature of the centre of the mass. Such even temperatures throughout the mass evidently eliminate the necessity for periodic turning, and ensure an even fermentation. This is in striking contrast to conditions obtaining in a small mass of cacao fermented under ordinary conditions, where much lower temperatures have been recorded in the surface and bottom layers than in the centre. Under ordinary conditions therefore, frequent mixing or turning is essential if an even fermentation is to be obtained. The success of these preliminary experiments suggests that the particular type of fermenting frame employed, or some modification adopting the same principles, may be of some practical importance to peasant holders of small cacao properties, who are faced with the problem of fermenting separate small lots of wet cacao. The solar fermenting frame seems definitely to provide a method whereby very small quantities of cacao can be successfully fermented, but in the present preliminary stage of these investigations, it is not possible to state definitely whether the method is economically feasible or worth while for the small holder. As far as capital and current expenditure is concerned, the method devised is much superior to other semi-artificial methods hitherto suggested for the curing of cacao, but the cost of construction of the rather elaborate frame used in these experiments is probably still somewhat beyond the means of the smallholder to whom the method should particularly appeal. The essential features of the method are a black absorbing surface and a glass-paned cover, whereby the heat energy of tropical sunlight is trapped and utilised to warm the fermenting mass of cacao. Further experiments are contemplated, utilising these principles, but constructing the frame in the simplest and cheapest manner. The preliminary trials so far carried out are purely experimental, and serve merely to draw attention to the possibilities of the method, which may be thought worthy of trial by agricultural officers in other cacao growing colonies. There are a number of points which still remain to be tested. For instance, Knapp has shown that cacao beans cured by Stevens' heat process were deficient in flavour and aroma after roasting, and it is possible that cacao fermented in the solar frame may have some such defect. Future samples should therefore be submitted to chocolate manufacturers for their criticism.

(VI) Summary.

(1) Experiments have been carried out with a suggested new method for fermenting small quantities of fresh cacao beans.

(2) A solar fermenting frame has been constructed, in which the heat energy of tropical sunlight is trapped and utilised to warm the fermenting mass of cacao.

(3) The mean temperature of the air surrounding the sweat-box inside the solar frame averaged 109°F. (43°C.) or 33°F. higher than the mean temperature of the outside air over a period of 24 hours.

(4) Small quantities of cacao (40 lb. to 60 lb. wet weight), fermented inside the solar frame, attained maximum temperatures of 121°F. to 124°F. (49°C. to 51°C.). Similar small quantities of cacao fermented outside under ordinary favourable conditions attained maximum temperatures of 108°F. to 111°F. (42°C. to 44°C.).

(5) Precautions taken to maintain a humid atmosphere inside the solar frame prevented the surface layers of the fermenting cacao from drying out unduly, and greatly improved the appearance of the final product.

(6) A Calabacillo type of cacao, fermented in the solar frame in lots of 40 lb. to 60 lb. wet weight, was equal or superior in appearance and commercial value to similar cacao fermented under estate conditions in lots of 1,000 lb. to 2,000 lb. wet weight.

(7) Important characteristics of cacao fermented in the solar frame are (*a*) almost complete freedom from mould, and (*b*) an even quality of the final product. The surface layers are free from mould, and as well fermented as the central portion, even though no turning was attempted, the fermenting mass being left undisturbed during the whole period of fermentation.

(8) The mean temperature of the bottom corner of the fermenting mass inside the frame was the same as the mean temperature of the centre of the mass. This even temperature evidently eliminates the necessity for periodic turning, and ensures an even fermentation.

(9) A Calabacillo type of cacao fermented in lots of 40 lb. to 60 lb. wet weight under ordinary favourable conditions outside the solar frame was inferior in appearance and value to cacao fermented under estate conditions. The low value of the small batch of cacao was largely due to the unsatisfactory fermentation of the surface layers, which were either mouldy or dried out and shrivelled.

(10) These preliminary results show that the solar fermenting frame offers a simple and effective method for successfully fermenting small quantities of cacao. The practical applications of this method to fermentation problems have been discussed. Further experiments have been planned.

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